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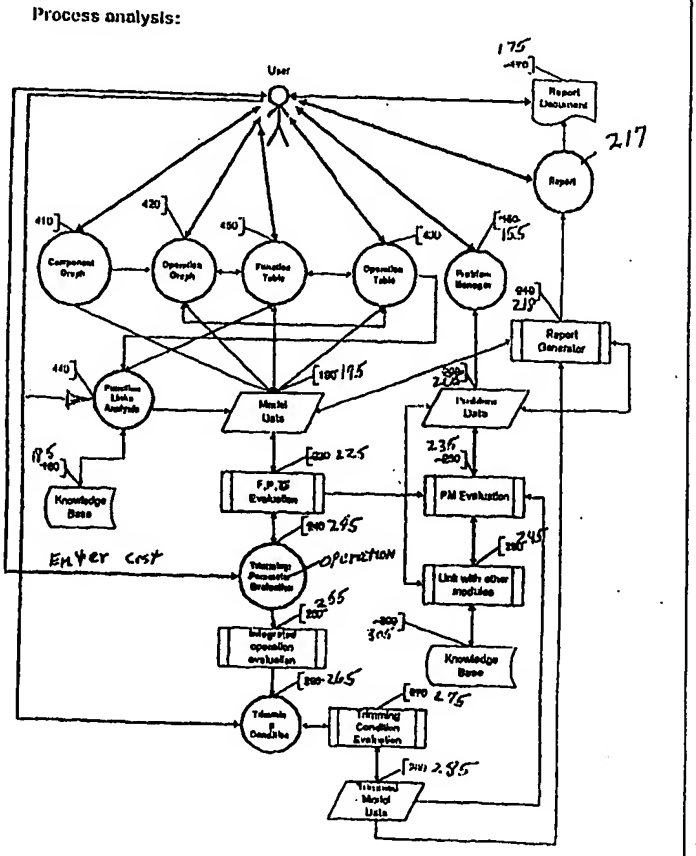
(54) Title: COMPUTER BASED SYSTEM FOR IMAGING AND ANALYZING A PROCESS SYSTEM AND INDICATING VALUES OF SPECIFIC DESIGN CHANGES

(57) Abstract

A computer system for analyzing and automatically modifying existing process system models that includes (i) an Initial Data stage (410, 420, 430, 450) that prompts the user to enter qualitative and quantitative objectives in designing or re-designing a process system; (ii) a Component model stage that displays, edits, and/or completes an image of the sequence of components produced or added during the process; (iii) a Process (Functional) Analysis stage (225) designating each function as harmful or useful, ranking each useful function, and performing a value link analysis of each function; (iv) a trimming routine (245) for eliminating or simplifying an operation in a process, and (v) a trimming routine that generates a recommended list, in priority, of problems to be solved to achieve the function trimming.



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TITLE: COMPUTER BASED SYSTEM FOR IMAGING AND ANALYZING A PROCESS SYSTEM AND INDICATING VALUES OF SPECIFIC DESIGN CHANGES

RELATED PATENT: This is a continuation-in-part application of co-pending U.S. Patent Application Serial No. 08/822,314, filed March 21, 1997, now U.S. Patent No._____, which is a continuation of U.S. Patent Application Serial No. 08/747,922, filed November 12, 1996, now abandoned.

BACKGROUND:

The present invention relates to engineering problem solving and design tools and more particularly to computer based systems for aiding engineers, scientists and the like to have a greater understanding of the products, processes, or machines they wish to improve and the technical problems related thereto that they wish to solve.

Great advancements have been made in the fields commonly known as computer aided design (CAD) and computer aided engineering (CAE). These computer based systems enable the designer to create detailed images and print-outs of the product or machine he/she is

designing or improving. With CAD, the designer can try many new designs or modifications of subsystems and components quickly and view the modified products immediately on the monitor or print-out. The CAD system also generates virtual 3-D images of the product or machine, enables in-space rotation of the product image and zoom through the product image interior.

Although CAD systems are a great designer tool for trying design changes quickly, they do not otherwise aid the designer in the evaluation and solving of technical engineering problems or conceiving new products or processes that provide new functional performance or the same functional performance with completely different engineering approaches. Accordingly, there has arisen a relatively new area of computer based engineering tools known as concept engineering computer based systems. These systems serve to increase the designer's inventive and creative abilities in solving engineering and scientific operational or functional problems and, in the course of such problem solving, induce the designer to invent new structural and functional concepts applicable to his/her design goals.

One such concept engineering computer based system is the Invention Machine™ LAB™ Software sold by Invention Machine Corporation of Boston, Massachusetts, that comprises a knowledge and logic based system that generates concepts and recommendations for solving engineering problems at the conceptual level. Various inventive rules or procedures are included and certain ones selected and presented to the user to consider in solving the user's current session problem. This system applies to all fields of physics and aids the engineer by solving engineering contradictions to reduce the tendency of user applied

engineering trade-offs. In addition, this system includes a large data base of physical, geometric, and chemical effects used in the past to solve other engineering problems and selected ones of the effects are presented to the user to consider for a solution to his/her current problem session. Lastly, this system includes a technology evolution and prediction capability that aids the user in understanding the dynamics of his/her product evolution and the logical next or future generation of the product or its function. This stimulates the user to think forward and extrapolate the dynamics of the technology life cycle and originate the next generation of technology.

Although the above conceptual engineering system has experienced much acceptance by the technical community, there is still a need for a computer based systems that aid the user in understanding the nature and value aspects of the current product, machine, or process the engineer wishes to design or re-design. In addition, there is a need for the user to be aided in formulating the statement of the most important technical problems for elimination of components or harmful actions between components of the object system being analyzed..

SUMMARY OF EXEMPLARY EMBODIMENTS OF INVENTION

One exemplary embodiment of the present invention pertains to a computer based conceptual engineering analysis software system and method (EAS) that satisfies the above described needs and provides other benefits described below. The EAS, according to the principles of the present invention, assists the user to input and displays a functional model of the object system under analysis, which functional model of an object, device, machine, or

other engineering system (hereafter termed "object system") includes the major components, supersystems, products and both useful and harmful interactions between them.

The EAS prompts the user to input data that enables the EAS to perform a parameter analysis of the various interactions. The EAS then analyzes the functional model elements, conducts an interaction parameter analysis, conducts an object system component function and problem and task significance ranking subroutine, and automatically displays recommendations of which components should be changed or eliminated from the object system to achieve the greatest redesign value and which functions should be transferred to the other remaining components.

The EAS includes an Initial Data routine that prompts the user to input analysis or session qualitative and quantitative objectives in re-designing an engineering system or object. After entering initial data, the EAS next prompts user to create an image of a functional model of the object system, learn what parts this object consists of, and how these parts interact with each other and with the environment. It is then possible to decide where the bottleneck is, what problems should be solved, and what is the urgency of the problems. Next a Functional Model routine displays an image of a functional model of the current session object and allows the user to edit it or complete the statement to generate the functional and interaction relationships of components of the current object system the user wishes to modify or redesign. The Functional Model routine includes three alternate modes to enable the user to build the functional model, namely, (i) a graph mode in which the user builds the functional model directly on the screen by entering boxes representing components, products and

supersystems or (ii) an expert or table mode in which the user is prompted to enter each component, product and supersystem. With such data entered, the EAS will display automatically the graphic form of the functional model if desired by the user.

The EAS also prompts user to apply to the functional model or an interaction matrix the harmful effects and useful interactions between specific components and any supersystems affected by and products produced by the object system. The EAS also prompts user to input the actual, desired and ideal values of harmful and useful interactions and parameter dependencies. The EAS then analyzes the model components and interactions and formulates a list of specifically numbered problems and sorts them according to urgency or priority.

The EAS provides a Trimming routine during which the object system functional model is analyzed, evaluated, and the functions and problems of each object system component ranked in importance. The user checks results and enters the cost of each component. The system re-analyzes the object system and recommends the components that can or should be simplified or trimmed (omitted) and certain trimming conditions.

The EAS conducts each analysis on either of two levels of depth as selected by the user, namely express (short analysis level) or advanced (detailed analysis level), as described below. Different levels of analysis for different interactions of the same object can also be conducted. After analyses are completed, the system presents the engineering system characteristics before trimming and after trimming and the percent of improvement of each characteristic.

As can be seen below, the EAS, according to the present invention indicates to the

user new and powerful information about the object, each component of the object, and each interaction between such components and each supersystem and any products produced or conveyed by the object. In addition, the EAS hereof in a Problem Management routine indicates to the user which components to try to modify or trim and eliminate their functions or transfer their functions to other components of the object system. The results also aid the user in identifying the core technical problems to be solved to produce the greatest value and the technical problems that disappear and need no solution if the trimming effort is successful. In addition, the EAS also includes the ability to generate a report at the end of each session describing all analysis steps, the original and trimmed object system, lists of detected problems, received concepts, object structure changes, feature transfer recommendations and results of the session.

The EAS, according to the principles of the present invention, also includes a Process System Analysis module (hereafter "PSA") that assists the user to analyze a process system intended to be modified or designed to improve a manufacturing, treatment, or other physical effectiveness, process (Process System) energy consumption, cost, time, number of steps, material consumption, pollution, space, or waste. The Process System Components and Operations, each Component being made, modified or added by a sequence of one or more Operations, each Operation being performed by a sequence of one or more Functions or steps.

The PSA module enables the user to analyze manufacturing, engineering, medical or technical processes from different perspectives and at several different levels of abstraction. The user first examines Components that are produced during a process, then the Operation that

produces each individual component, and finally the various Functions that make up each discrete operation.

The PSA constructs graphical models of Components that are produced in the process, as well as a graphical Function model. Process (Link) Analysis is performed, and a new, powerful Trimming routine is provided.

With PSA, the user can define project objectives and their relative importance, which change the Trimming factors and subsequent recommendations for Trimming. Objectives can be evaluated one operation at a time, offering a level of scrutiny not previously available. In addition, there is a capability for establishing Trimming Variants, in which the user can define multiple paths for Trimming in order to find the optimum approach.

The Process System Analysis module includes five major routines:

1. Initial Data stage that prompts the user to enter qualitative and quantitative objectives in designing or re-designing a Process System.

2. Component Model stage that displays an image of the sequence of Components produced or added during the process and that allows the user to edit or complete the Component Model display. The user begins this stage by drawing a model structure of the operations and their sequence. Each process has a hierarchy: a process can be reduced to components, which are produced during the process; the components can be further reduced to operations that produce them. The operations are further made up of functions, each consisting of three parts: an element or tool, an action, and an element or tool that receives the action. The user can start the analysis on the highest level of the hierarchy and analyze the lower levels

of the hierarchy subsequently, if necessary.

3. Process (Functional) Analysis stage prompts the user to enter data for the functional and interaction relationships of the Functions and Operations that produce each Component of the Process System and to identify and designate each Function of each Operation as harmful or useful. This routine further enables the user to (i) identify tools and parts of components used or addressed during the respective operation, (ii) rank each useful Function according to the value of its contribution to the respective Operation, (iii) display graphically the logic links between Functions of each Operation and other Operations. The routine enables the user to make a contribution value link analysis of each Function including the level of the Function performance (insufficient, excessive), define parameters and designate their values and their dependencies in time and space, and compare between actual and required parameters.

Thus, after building the model graphically, user can analyze each action thoroughly through this stage. PSA supports two levels of link analysis. The primary level, called actions analysis, requires very little information for the description of the action. Each function is defined according to one of four types in just a few words. Useful actions are classified according to their level of function performance: normal, excessive, and insufficient, and scored on a scale. Harmful actions are also scored from least harmful to most harmful.

The second level of analysis is advanced link analysis, which allows the user to define functional performance in terms of associated parameters. Parameters analysis includes parameters of the actions. For every useful action. each parameter actual and required values, within dependencies of time, space, or other dimension, are compared. Actual and admissible

parameter values are compared for harmful actions. The PSA determines the degree of discrepancy between actual and required values of useful parameters, or between actual and admissible values of harmful parameters. A description of how these discrepancies influence the effectiveness of the process can be defined by the user.

4. Trimming is a PSA routine for eliminating or simplifying an operation in a process, while retaining or transferring its useful functions. The Trimming stage is based on the benefit that a process can be simplified by eliminating certain component operations of the process, while redistributing the operations' useful functions to other operations or to non-processed components. Redistributing functions means fewer and simpler operations. Eliminating operations means there are fewer problems to be solved.

Trimming routine calculates the values of and ranks the Operations or Functions to identify the best candidate for elimination. This routine develops the Process Function Rank for each Operation, its Process Problem Rank and Cost. The Trimming routine then presents a set of rules by which the modification or elimination or transfer of the Function can be analyzed and selected depending upon the type of Function being considered.

Trimming stage provides the following benefits:

1. If an operation is eliminated, all harmful actions associated with the operation are also eliminated.
2. Trimming the operation makes the process less expensive. The operation does not need to be produced or performed.
3. If an operation is not trimmed, one or more functions are transferred to other

operations, and the first operation becomes simpler and less expensive.

4. The process structure becomes optimized.

5. Trimming conditions are methods of redistributing the useful functions of an eliminated element or operation.

6. PSA will discourage the removal of a useful function, without transferring its action to another operation or to a non-processed component. Thus, PSA provides trimming conditions that correctly transform the process structure. All useful actions are performed by the remaining components.

5. Problem Manager routine manages the problem statement and displays, and stores parts of the entire session and generates a list of problems to be solved in achieving the redesign objectives. In addition, Problem Manager ranks each problem to display the relative importance in solving such problems. PSA, accordingly, collects this information, correlates it with the components of the process, generates a list of problems, and defines their urgency or significance. In this way, the PSA makes significant recommendations to the user about which problems should be solved first for maximizing the benefits of process redesign and of meeting the user's objectives. Problem Manager can collect organize, and print out a report summarizing the entire project, including all stages of PSA if desired.

DRAWINGS:

Other and further aspects, benefits and objectives of the present invention will become apparent with the following detailed description when taken in view of the appended drawings in which:

Figure 1 is a block diagram of one exemplary embodiment of an engineering analysis system (EAS) according to the principles of the present invention.

Figure 2 is a diagrammatic representation of a personal computer which can form a part of the EAS and enable user interaction described below.

Figure 3 is a flow diagram of the major sub-sessions or stages of EAS analysis.

Figure 4 is a block diagram of the Action Task significance routine.

Figure 5 is a block diagram of the component Problem Rank routine.

Figure 6 is a block diagram of the routine for calculating a task significance for a new technical problem arising from a EAS recommended Action for Transfer.

Figure 7 is a block diagram of the routine for generating the EAS component trimming recommendation.

Figure 8 is a visual display device screen illustrating a display for inputting data and displaying initial project data.

Figure 9 is a visual display device screen illustrating a display for inputting data and displaying advanced project data.

Figure 10 is a visual display device screen illustrating a display for inputting data and displaying further advanced project data.

Figure 11 is a visual display device screen illustrating a display for inputting data and displaying the team member file.

Figure 12 is a visual display device screen illustrating a display for inputting the data and displaying the graph mode functional model of a water pump as the object system.

Figure 13 is a visual display device screen illustrating a display for inputting data and displaying link analysis for the functional model of Figure 12.

Figure 14 is a visual display device screen illustrating a display for inputting data and displaying parameter quantitative value link analysis.

Figure 15 is a visual display device screen illustrating a display for inputting data and displaying parameter qualitative value link analysis.

Figure 16 is a visual display device screen illustrating a display for inputting data and displaying time dependency link analysis.

Figure 17 is a visual display device screen illustrating a display for inputting data and displaying space dependency link analysis.

Figure 18 is a visual display device screen illustrating a display for inputting data and displaying Parameter dependency.

Figure 19 is a visual display device screen illustrating a display for inputting data and displaying data similar to Figure 13 but for a different. harmful action analysis.

Figure 20 is a visual display device screen illustrating a display for inputting data and displaying the user choice of component trimming.

Figure 21 is a visual display device screen illustrating a display for inputting data and

displaying trimming parameter evaluation functional rank.

Figure 22 is a visual display device screen illustrating a display for inputting data and displaying trimming parameter evaluation problem rank.

Figure 23 is a visual display device screen illustrating a display for inputting data and displaying trimming parameter evaluation cost evaluation.

Figure 24 is a visual display device screen illustrating a display for inputting data and displaying trimming integrated component evaluation.

Figure 25 is a visual display device screen illustrating a display for inputting data and displaying trimming condition.

Figure 26 is similar to Figure 12 and displays the trimmed functional model of the object system.

Figure 27 is a visual display device screen illustrating a display for inputting data and displaying the expert mode analysis level.

Figure 28 is a visual display device screen illustrating a display for inputting data and displaying the expert mode product element definition.

Figure 29 is a visual display device screen illustrating a display for inputting data and displaying the expert mode supersystem element list.

Figure 30 is a visual display device screen illustrating a display for inputting data and displaying the expert mode object component definition.

Figure 31 is a visual display device screen illustrating a display for inputting data and displaying expert mode level of analysis hierarchy.

Figure 32 is a visual display device screen illustrating a display for inputting data and displaying expert mode matrix of interaction.

Figure 33 is a visual display device screen illustrating a display for inputting data and displaying browser mode functional model table.

Figure 34 is a visual display screen illustrating a display screen for inputting data and displaying the Problem Manager task.

Figure 35 is a visual display screen illustrating a display screen for inputting data and displaying the first screen of the feature transfer routine.

Figure 36 is a visual display screen illustrating a display screen for inputting data and displaying feature transfer object data.

Figure 37 is a visual display screen illustrating a display screen for inputting data and displaying feature transfer Integrated Result.

Figure 38 is a visual display screen illustrating a display screen for inputting data and displaying feature transfer Recommendation.

Figure 39 is a visual display screen illustrating a display screen for inputting data and displaying feature transfer advanced alternative approach.

Figure 40 is a visual display screen illustrating a display screen for inputting data and displaying feature transfer alternative approach parameter analysis.

Figure 41 is a visual display screen illustrating a display screen for inputting data and displaying feature transfer alternative approach function analysis.

Figure 42 is a visual display screen illustrating a display screen for inputting data and

displaying feature transfer alternative approach element analysis.

Figure 43 is a visual display screen illustrating a display screen for inputting data and displaying feature transfer alternative approach feature analysis.

Figure 44 A - E are representations of EAS trimming rules.

Figure 45A is a flow diagram of the major sub-sessions or stages of the PSA system.

Figure 45B is a flow diagram of the major routines of the Process Analysis stage of Figure 45A.

Figure 46 is a block diagram of the PSA system.

Figure 47 is a PSA visual device screen illustrating a display for entering data and displaying initial PSA project data.

Figure 48 is a PSA visual device screen illustrating a display for entering data and displaying initial PSA team member and project data.

Figure 49 is a PSA visual device screen illustrating a display for entering data and displaying component model data in graphic form.

Figure 50 is a PSA visual device screen illustrating a display for entering data and displaying component model data in table form.

Figure 51A is a PSA visual device screen illustrating a display for entering data and displaying Operations data.

Figure 51B is similar to Figure 51A for entering and displaying Function data.

Figure 52 is a PSA visual device screen illustrating a display for entering data and displaying function type and other function data.

Figure 53 is a PSA visual device screen illustrating a display for entering data and displaying function type and other function data.

Figure 54 is a PSA visual device screen illustrating a display for entering data and displaying function type and other function data.

Figure 55 is a PSA visual device screen illustrating a display for entering data and displaying function type and other function data.

Figure 56 is a PSA visual device screen illustrating a display for entering data and displaying Link Analysis data.

Figure 57 is a PSA visual device screen illustrating a display for entering data and displaying Link Analysis significance data.

Figure 58 is a PSA visual device screen illustrating a display for entering data and displaying Function Rank data.

Figure 59A is a PSA visual device screen illustrating a display for entering data and displaying Problem Rank data.

Figure 59B is a PSA visual device screen illustrating a display for entering data and displaying cost of each Operation.

Figure 60 is a PSA visual device screen illustrating a display for entering data and displaying Integrated Component Evaluation data.

Figure 61 is a PSA visual device screen illustrating a display for entering data and displaying default and user defined and entered trimming factor ranking algorithm.

Figure 62 is a PSA visual device screen illustrating a display for entering data and

displaying Trimming conditions data including function transfer.

Figure 63A is a PSA visual device screen illustrating a display for entering data and displaying Trimming conditions data including Trimming data.

Figure 63B is a PSA visual device screen illustrating a display for entering data and displaying Trimming conditions data including Trimming data.

Figure 64 is a PSA visual device screen illustrating a display for entering data and displaying Trimming conditions data including dropping an action data.

Figure 65 is similar to Figure 51A and 51B illustrating the modified and improved process model with functions transferred, trimmed, and modified.

Figure 66 is a PSA visual device screen illustrating a display for entering data and displaying Problem Manager including problem statements and problem significance data.

DESCRIPTION OF PREFERRED EMBODIMENTS:

With reference to Figures 1 and 2, one preferred exemplary embodiment EAS 10 resides on a personal computer 12 that includes a CPU 14, monitor 16, keyboard, mouse 18, and printer 20. The EAS program may be stored on a portable disk and inserted in disk reader slot 22. Computer 12 can be conventional and be of any suitable make or brand. However, minimum performance specification for computer 12 should be Intel 486 with 20 meg Hard Disk available, 4 meg of RAM, 75 MH clock speed. If paper copy of the EAS session is desired, printer 20 should also be provided. Other peripherals and modem/network interfaces can be provided as desired.

With reference to Figure 1 and the legend in Figure 3, an EAS session has four main object system analysis stages termed Initial Data, Functional Model, Training, and Problem Solving. As the user develops the session, the user can return to and edit or modify any stage data at any time and the EAS will modify the entire project session accordingly.

The user starts a new session by accessing the EAS. The EAS prompts the user to enter the first stage "Project Data." The user can enter initial data with use of the keyboard and/or mouse. During the Project Data stage the user enters initial project data to the report unit 215 and report generator 210. Report unit 215 functions to display elements of the final report on monitor 16 and enable the user to edit various parts of the report. Report generator 210 coordinates the project objectives and rank with model data unit 190 and processes the model data, problem data and trimmed model data into results, as described below, and generates the final report for display by report unit 215.

During the Functional Model stage, the user inputs data to graph unit 100. Unit 100 serves to display a graphic representation of the functional model of the object system under analysis. The user draws a symbol such as a box to represent each component of the object system functional model and a line between boxes to represent each interaction between components. Boxes and lines (links) can be labeled on screen and marked as useful or harmful as determined by the user. Supersystems, products, and their links with specific components are also drawn on screen.

If the user prefers, he/she can call up the expert unit 110 that presents a set of dialog boxes that lead the user through a set of table entries in table unit 120. The model data unit

190 will input data to the graph unit 100 and once the entries to table unit 120 are complete, graph unit 100 will automatically draw the functional model for the user.

Conversely, if the user draws the functional model using graph unit 100 and then accesses table unit 120, the functional model will be represented in table form automatically. The user can edit any data of the functional model in either the graph unit 100 or table unit 120 format.

Model data unit 190 is a data storage facility and obtains and feeds data to the many units generally shown in Figure 1.

As described below, the user calls up a link analysis unit 140 as part of the Functional Model Stage. This unit 140 enables the user to select for each link in the functional model a short description of the action link, such as compress, move, heat as well as its characteristic such as harmful, insufficient, normal, or excessive. This is done for each link in the functional model and the data stored in model data unit 190.

The user can, for any link, implement an advanced link analysis routine in advanced link analysis unit 130 that enables the user to detail the character of the action by means of comparing actual values of an action with required values of the action. These values are also stored in model data unit 190. This advanced link analysis unit 130 enables four different types of data entry for the actual value and required value of an action parameter. These are Value, Time Dependency, Space Dependency, and Parameter Dependency. As described below, Parameter Value data can be represented either as qualitative relative ratio values or as quantitative values. For example, if the action link is "compress" between two components, the

actual PSI and required PSI values can be entered in unit 130. In addition, the actual and desired tolerances can be entered such as ±2 psi and ±1 psi, respectively.

The Time Dependency data is entered to unit 130 by the user selecting the actual and desired parameter values over the desired duration of the action. Space Dependency data is entered to unit 130 by the user selecting the actual and required parameter value at various points in the space or distance through which the action occurs. Lastly, the user enters into unit 130 Parameter Dependency data for the actual and required link parameter as it relates to a separate other parameter in the object system functional model entered (named) by the user.

Although the above four detailed analyses are available, the user need not select them all and can select a "not defined" button which removes that analysis from consideration by the EAS.

All user entered Link Analysis and Advanced Link Analysis data is stored to the model data Unit 190.

Once satisfied, the user initiates the Trimming routine stage.

Trimming is a routine for elimination or simplifying a component or action from an object system while retaining its useful function.

An object system usually includes harmful actions or useful actions which are not optimally fulfilled. Every disadvantage presents a problem that should be solved. Also, distribution of functions among the elements might not be uniform. Some of them might perform insignificant functions and others are overloaded with functions.

The EAS Trimming routine provides analyses for the redistribution of functions and

elimination of components from an object system while retaining the components useful functions. Components can be eliminated and their functions transferred to other components or supersystem elements. This process increases the function or decreases the cost of the object system or both, thus increasing the object system value.

The following benefits are provided by trimming:

1. If a component is eliminated, all the harmful actions connecting with this component are also eliminated.

2. Trimming the components lowers the cost of the object system since it is not necessary to produce this component.

3. If a component is not trimmed, but one or more functions are transferred to another component, the first component becomes simpler and less costly.

4. The object structure becomes more optimal and uniform.

Trimming conditions are methods of redistributing the useful functions of an eliminated element. Since it is not practical to remove a component performing some useful function, the action of this component should be transferred to another element.

A component can be eliminated if:

1) its action is performed by another component or supersystem element;

2) its action is performed by the component which receives the action;

3) the component which receives the action is also eliminated.

If the trimmed component was affected by another component or supersystem element this action must also be transformed.

There are two ways to transform an action applied to a trimmed element:

1) action can be applied to another element;

2) action can be deleted.

To trim an element, the EAS enables the user to:

1) choose an element for trimming;

2) apply trimming conditions;

3) transform the action.

EAS Trimming routine provides two procedures for choosing an element to trim:

1) use of component evaluation

2) open choice of component

Open choice of component allows the user to choose the component based on the component statistics, analyze the information given by EAS and recommend a decision as to which component should be trimmed. Figure 44 A-E shows various EAS rules for elimination and transformation and how the trimmed or transformed component or action would be displayed on the functional model and trimmed functional model.

With use of component evaluation EAS suggests the component for trimming. This is based on its standard evaluations of the problem rank (P), function rank (F), and cost (C), of the components, as entered by the user. EAS then creates a graph to illustrate its calculations. When it plots the components on the graph, EAS places the component with the highest functional rank at the top of the vertical axis. The functional ranks of all the other components are calculated as a percentage of this maximum rank. The procedure is the same for the

horizontal axis, which shows the combination of problem rank and cost.

As seen below, the user accesses Trimming: Parameter Evaluation unit 240 and inputs data that ranks the importance of the function (for example, on a scale of 1 to 10) of each functional model component and ranks the problem or harmful effect (for example, on a scale of 1 to 5) associated with each component. The cost of each component in terms of the percentage of the overall cost of the object system under analysis is also entered to unit 240. If more than one project team member was entered during the Initial Data routine stage, then all team members (users) must input to unit 240 their concurrences or agreements to this data. Once a consensus is reached, Function, Problem Rank, Task Significance (TS) Evaluation routine unit 220 accepts this data from unit 240. Unit 220 also receives constantly the Functional Model Data from unit 190. Unit 220 calculates and determines the EAS Functional Rank of each component, its EAS Problem Rank and EAS Task Significance as described below and transmits these values to Integrated Component Evaluation routine unit 250. Unit 250 calculates the EAS functional contribution of each component as a percentage relative to the others and the EAS problem and cost ranking again as a percentage. Lastly, unit 250 determines the ranks of candidacy for trimming (elimination) and represents its recommendation for each component, such as "A" "B" "C" or "D", D being the highest ranking for trimming and A being the lowest candidate rank for trimming. Detailed ranking can be represented in graph form with F on one axis and P +C (problem + cost) on the other. The component trimming candidacy rank can be represented by a dot on the graph located anywhere in or on the line between any of four quadrants A-D as described below.

The Integrated Component Evaluation routine is seen in Figure 7. Problem rank from unit 220 is entered to unit 430. The user enters the component cost in unit 440 through unit 240. Function rank is calculated in unit 220 as described below and entered to unit 450. Unit 460 receives this data and standardizes the values of F, P and C as a percentage or ratio summing to 100%. The P + C value is then standardized again.

Then EAS unit 250 sorts all components in the object system in accordance with the following table.

		Level of P+C	
		Low level of P+C	High level of P+C
Level of F	High level of F	A group	B group
	Low level of F	C group	D group

The unit 250 then recommends to the user ranked components for trimming first from D group, than from C, B, A. If there are several components inside one quadrant, EAS unit 250 suggest first the component with the smallest relation F/P + C.

This information is represented on screen at unit 255 and enables the user to edit the F, P, TS information as desired. The information is also provided to Trimming Condition Evaluation routine unit 270. Unit 270 analyzes the action between two components one of which is to be trimmed and suggests another component to which the trimmed function might be transferred. This recommendation can be edited by the user or accepted or represented further as described below.

Function rank of a component is designated as follows:

Every object system interacts with a supersystem or product. The graphic or table

representations of the functional model will display one or a chain of components and links or interactions. The component linked to the product or supersystem has the highest rank and the component furthest from the product or supersystem has the lowest rank. If a component performs several useful actions (such as a piston that both compresses and functions as a valve) the function rank will be calculated as the sum of the action ranks. Harmful actions are ignored in calculating function rank.

Task Significance (TS) is automatically calculated in a subroutine of unit 220. The result of this calculation is termed Action Task Significance, see Figure 4. As seen below, each action can be described by several parameters entered by the user, namely Value TS 350, Time Dependency TS 360, Space Dependency TS 370, and Parameter Dependency 380. When accessing unit 350 the user can select to enter qualitatively through Qualitative VTS (Value TS) unit 390 or quantitatively through Quantitative VTS (Value TS) unit 400. The calculation by unit 350 of Value TS is provided in accordance with the following formula:

$$VTS = k_i \frac{|V_r - V_a|}{IV_r}$$

VTS - value task significance,

k_1 - coefficient of objective importance (If problem is associated with objective, that has high importance, value of coefficients high);

V_r - required value of parameter

V_a - actual value of parameter

IV_r - admissible deviation of required value.

The calculation by unit 360 of Time Dependency TS, Space Dependency TS and Parameter Dependency TS is provided in accordance with the following formula:

$$DTS = k_i \frac{\sum_{i-1}^{n} \left(|D_{ri} - D_{ai}| \right)}{nID_r}$$

DTS - dependency task significance (the formula is similar for all kinds of dependencies);

k_i - coefficient of objective importance (If problem is associated with objective, that has high importance as entered by user in Initial Data stage, value of coefficient is high);

D_{ri} - value of i-point of required dependency for parameter;

D_{ai} - value of i-point of actual dependency for parameter;

ID_r - admissible deviation of required dependency;

n - number of point.

The above calculations are for useful actions. For harmful actions, the formulas will be the following:

$$VTS = k_i \frac{|V_{ac} - V_a|}{IV_{ac}}$$

VTS - value task significance,

k_1 - coefficient of objective importance (If problem is associated with objective, that has high importance, value of coefficient is high);

V_{ac} - acceptable value of parameter

V_a - actual value of parameter

IV_{ac} - admissible deviation of acceptable value.

$$DTS = k_i \frac{\sum_{i=0}^{n} \left(|D_{aci} - D_{ai}| \right)}{nID_{ac}}$$

DTS - dependency task significance (the formula is similar for all kinds of dependencies);

k_i - coefficient of objective importance (If problem is associated with objective, that has high importance as entered by user in Initial Data stage, value of coefficient is high);

D_{aci} - value of i-point of required dependency for parameter;

D_{ai} - value of i-point of actual dependency for parameter;

ID_{ac} - admissible deviation of required dependency;
$i = 0...n$ - current point of dependency;
n - number of point.

Unit 220 also includes a subroutine for calculating the action Problem Rank (P), see Figure 5. Problem rank is calculated in accordance with the following formula:

$$P = \sum_{i=1}^{n} TS_u + \sum_{i=1}^{m} TS_h$$

P - problem rank;
TS_u - task significance for useful action;
TS_h - task significance of harmful action;
n - number of useful actions performed by component;
$i = 0...n$;
m - number of harmful actions performed by component;
$i = 0...m$.

The original user-entered Functional Model Data is also entered to Trimmed Model Data Storage unit 280. This Trimmed Model data is modified by or edited by the results data of unit 270. Unit 280 applies trimmed model data to Report Generator 210 that generates Trimming Results data and applies it to Report Unit 160 that presents it on screen to the user. Since unit 210 receives and processes both the Model Data from unit 190 and the Trimmed Model Data from unit 280, the Trimming Result report shows a variety of characteristics of the session object system before trimming and after trimming and a percentage improvement of each characteristic after trimming.

These characteristics can include, for example, the number of components in the session object system, number of harmful actions, total component costs, number of links, number of

useful actions, and useful action components.

The EAS anticipates that certain technical problems will need solution in order to trim one or more components from the session object. The EAS automatically formulates and accumulates the problems that should be solved. The number of problems can be rather large. So the EAS calculates their significance and sorts them accordingly. To accomplish this, the Problem Manager routine unit 150 enables the user to input data related to the functional model and the action or components desired to be trimmed. The problem Manager unit 150 prompts the user to enter a full and short description of the problem and select the problem type such as deviate negative effect or increase useful effect. Further, the user enters the significance, if the component can be trimmed, and the group or type of benefit objective of trimming, such as simplify, efficiency, or quality increase. Each component and action of the functional model is assigned an identifying number by unit 150. Problem Manager data is stored in Problem Data unit 200 and processed by Problem Management (PM) Evaluation unit 230 that receives trimmed model data from unit 280 and task significance data from unit 220.

The Problem Manager routine also aids the user in evaluating different designs of the same component to optimize the design of that component in the object system functional model. For this purpose, unit 150 and unit 230 include a Feature Transfer: Object Data prompt that enables the user to enter the quantitative parameters of two or three different models of the same component (such as the actual and two additional known piston designs) as well as the technical and theoretical limits of each parameter. Unit 230 processes the trimmed model data, F,P,TS data, and problem data and calculates an index or quantitative ranking number for each

design model and recommends one of the component design models for analysis and improvement and lists the characteristics to be improved. Unit 230 also generates a Feature Transfer: Recommendation on how to begin the problem solution. For example, a piston leakage parameter is to be improved and a piston with better leakage characteristic had been analyzed, the unit 230 recommends to the user to define the technical effect that enabled the leakage resistance to be improved in the alternate piston. If the user needs help in considering a number of technical effects associated with pistons, the user can select a box that will represent on screen a number of technical effects related to pistons and select the one that contributed to the better parameter achievement by the alternate piston. The unit 150 then formulates the technical problem statement for the user, as described below. This technical problem statement is presented to the user through unit 150 and it and all problem data is entered in Report Generator unit 210. Problem data is also conveyed to a problem solving model interface 290. The technical problem solving module can be the above mentioned Invention Machine Software.

With reference to Figure 1,6 and 7, Problem Manager routine unit 230 can process two types of problems:

1- problems related to actions between elements (action problem)

2- problems associated with trimming procedure (trimming problem)

Action problems are processed in unit 230 using the Action TS data from unit 220 as described above. Trimming problems are identified or connected with a trimmed component. If the component is trimmed the problem connected with that component should not be solved.

The following rules apply to component trimming in unit 270:

Component can be eliminated if:

1- its action is performed by another component or supersystem element;

2- its action is performed by the component which receives the action;

3- the component which receives the action is also eliminated.

If trimmed component was affected by another component or supersystem element this action also must be transformed. There are two ways to transform an action applied to a trimmed element:

1- action can be applied to (transferred) another element;

2- action can be deleted.

The user chooses one of the trimming conditions through unit 150.

If the Action can be transferred, then the subroutine of Figure 6 is run in unit 230. Here unit 230 calculates the sum of the problems of I group associated with the component (box 420) and generates a new problem of action transfer with significance equal to this sum (box 430).

The detailed process steps for a typical EAS session will now be described using a water pump as an example of an object system. As stated above and with reference to Figure 8, a session begins with EAS prompting the user to enter certain basic information into a Project Data File, such as Project Name; Name of engineering system for re-design, such as "PUMP" in this example; Life Stage of the Pump, selected from a menu such as developmental, operational, or maintenance; Initial Situation Description, such as "Pump has low value because of high

maintenance from frequent clogging and corrosion;" and Objectives. Limitations, such as "reduce clogging and corrosion without significant increase in pump cost."

If Advanced button is selected, Figures 9 and 10, the EAS will prompt the user to optionally enter detailed objectives such as the unit of measurement, the current value, the desired value, and whether the value should increase or decrease as a session objective. This Project Data field provides a list of possible objectives and limitations. The user may select the items from this list which apply to the current project. This list may also be customized by the user using add and remove buttons. Each of the categories for the objectives and limitations should be ranked according to their importance. EAS will use this ranking later when it calculates which problems are most urgent and which components can be trimmed.

If team members are to work on the project, they can be listed in the team file, Figure 11, and a final report can only be generated with the computer concurrence of all these members.

The first step in using EAS to analyze an object system is to draw an object structure. The components (parts of the object) will be shown on screen. Each object system has a hierarchy and is decomposed into units; the units are decomposed into parts and so on. It is preferred to start the analysis on the highest level of the hierarchy. If necessary, EAS can analyze the lower levels of the hierarchy simply by breaking components into sub-components. The interaction of the object with the elements of the environment, products and supersystem elements, should also be shown.

Accordingly, the EAS prompts the user to open a second file called Functional Model in

which the user can input data and the EAS will display the object system functional model. The user can select a Graph mode Figure 12 or Expert step-by-step mode. In the graph mode, the user defines (draws boxes and labels them) every subassembly or component in the object system, such as the cylinder, piston, valve and lever of the pump. The pump product "water" 14 is also identified along with the supersystem "Air" 10 and "Dust" (meaning dirt) 12.

Once all such elements are represented, the user enters all useful interactions between elements such as "compress" between piston image and water image and "direct" between the cylinder and piston images and "move" between the lever and piston images. Also. the EAS enable the user to represent harmful effects of element interaction such as "clogging" between the dust and valve images and "corrode" between the supersystem air image and the cylinder image. The interactions can be represented in different colors such as blue or black for useful and red for harmful.

If the user is a beginner in analysis or if the user likes a step-by-step analysis, then the user can select the Expert mode and the EAS units 110 and 120 will initiate a routine to provide a series of dialog boxes in table form that leads the user through the data entry steps described above. This routine enables an alternate method of inputting the functional model data as described above. The first dialog box displayed for Expert is shown in Figure 27 in which the user can select a "basic" or detailed and advanced analysis or a "short" or less detailed analysis. If the short analysis, no information about harmful actions will be permitted by the EAS. but parameters, values and dependencies can be entered for useful actions. Once the analysis mode is selected a dialog box, Figure 27 enables the user to enter the supersystem product or media

with which the object system produces or interacts. In the example below the object system (pump) interacts with the product "water" so water would be entered. Next the Expert routine displays a dialog box, Figure 28 calling for entry of additional syspersystem elements, such as air, dirt, or other environmental elements which interact with the object system. Each element is added to the dialog box by the user. Next, the Expert routine displays a dialog box showing boxes arranged in a hierarchy, see Figure 29. The names of the object system and product and all other supersystems automatically appear in the top row of boxes. The user enters each major component in the next row of boxes and, if desired, each sub-component in the boxes below a component. All data in this dialog box can be edited as desired and previous screen data will be changed accordingly.

Next the user chooses a level of hierarchy to be analyzed. The I level simply enables the EAS to analyze the level above the component level. The II level enables a first component level analysis and the III level enables all levels to be analyzed. See Figure 31.

The Expert route next displays a legend of interaction among all components, elements and products and displays a legend of four interactions across the lower portion of the matrix. See Figure 32. Note all components, elements, and products appear along both X and Y axis. The user can click on any intersection, box for X and Y entries, select any ones of the four interactions along the bottom and then click on one of the element names to save the interaction selections. These selected interactions will appear in the respective box intersection as shown in Figure 32. Interactions can be deleted (edited) from a box by clicking on one of the axis entry names, then clicking on the action to be deleted. All interactions within all boxes

can be entered in the same way. Note the four interactions include "useful", "useful insufficient","useful excessive" and "harmful", each being associated with a different symbol or color, preferably red for harmful.

Once the above data is entered, the user can click on Finish to save to Model Data unit 190 and click on Browser that displays the table of Figure 33. Here the user can enter each action name between each product, component, and/or supersystem and enter the Rank of interactions as harmful (H) or basic (B), auxiliary function rank A_1, A_2 --- A_n enter the parameter to be analyzed as described below and the value or dependency discrepancy as described below. This data is stored in unit 190 and at this point the functional model can be displayed by the EAS via unit 100, see Figure 12, and the user is ready to implement the Link Analysis and Advanced Link Analysis described below. After entering the data on tables and the like, the EAS will automatically draw the diagram of the object system as shown in Figure 12. It will be noted that more than one action can be entered between components, such as the three different actions shown in Figure 12 between "cylinder" and "piston".

The EAS Functional Model can then prompt the user to perform a Link Analysis followed by an optional Advanced Link Analysis, so that each link or interaction between all elements are examined one at a time. The Link Analysis presents to the user the image of two elements and the selected link or interaction between them. See Figure 13 that shows the user data input capability for the analysis of the "compress" interaction between piston and water of the present session. The Link Analysis prompts the user to identify the link as harmful or useful, the level rank of the function of the interaction to the overall function of the object

system. This Level includes the user choices Excessive, Normal, and Insufficient and represents the first or basic level of link analysis. If more detailed analysis of the link is desired, the user enters the parameter(s) to be entered and selects Advanced. See Figures 13 and 14. The Advanced Link Analysis lists each parameter, e.g. "pressure", and prompts the user to initiate data entry for the following EAS analysis:

Quantitative Value

Time Dependency

Space Dependency

Parameter Dependency

In the example session, see Figure 14, Value screen prompts the user to indicate the qualitative or quantitative nature of the value and input the actual pressure value, the required pressure value plus or minus the tolerance. High, middle, or low significance of this value can also be selected.

Alternatively, if actual numbers are not known, the qualitative value can be selected and the user indicate actual and required pressure value by a relative slide button adjustment, see Figure 15.

Further analysis and data input is achieved for time, space and parameter dependency, see Figures 16, 17, and 18. In each of these screens, two graphs are presented both with "pressure" forming the X axis and a user named axis as the Y axis. The left graph is the actual behavior of the link parameter and the right graph is the Required Behavior. An Acceptable Deviation slide button allows the user to set this factor for the required Required Behavior chart. The user enters data by placing the cursor on each graph circle on the Y axis and raising

it to the desired level on the X axis. As seen in Figure 17, the pressure actually rises with, for example, respect to the cylinder length whereas the user requires a constant pressure over the cylinder distance. In Figure 16, a different pressure duration of stroke characteristic is desired with a set deviation than actually present in the object system.

In each of these cases, there may be a parameter that has no fixed value and the value depends on the circumstances. In this case, the user would select "not defined" such as seen in Figure 18 for Parameter Dependency. When the user completes each step of the Link and Advanced Link Analysis, the ""OK"" button is selected. Regardless of the type of data entered, the data is stored, but can be edited at any time as described above in relation to Figure 1 description. The above Link Analysis can be done and screens are provided for each link or interaction between components. For example, Figure 19 shows the Link Analysis for "corrode" between the supersystem "Air" and the "Piston". Note the "Harmful" button has been selected. The Value, Time, Space and Parameter dependencies analyses screens (not shown) are the same as for Figures 14 – 18 enabling the user to enter data for a harmful action.

The EAS enters the Trimming Stage, Figure 3, by presenting the screen of Figure 20 in which the user can select to have the EAS recommend the component or components to be trimmed using cost, problems, and functional evaluations of the components from unit 220 or "open choice" meaning the user will decide which components to recommend to trim.

If the EAS Trimming recommendation is selected, the Trimming: Parameter Evaluation screen, Figure 21, displays through unit 240 the Problem Rank for each component of the object system. Team members are also listed and when each member reviews and concurs with the data displayed the user selects the consensus button. Next the Problem Rank is displayed

for each component, Figure 22 and unit 220, Figure 5 and the calculation of Problem Rank above, and again the consensus selected. Lastly the Cost Evaluation is displayed, Figure 23, for each component as a percentage of the entire cost of the object system, and again the consensus indicated. It should be understood that the data displayed in Figure 21, 22, 23 can be edited and all previous EAS calculations will be changed accordingly. This editing capability will contribute to the team consensus being reached.

Next, the EAS displays the Integrated Component Evaluation Table and/or graph of Figure 24 where each component has its Function and Problem + Cost rated as a percentage relative to the other components, as described above, then EAS assigns an A – D ranking or dot location on a 4-quadrant graph as shown. Each component can be highlighted for highlighting its dot on the graph while other dots for other components remain light. This display is associated with unit 255 of Figure 1. As seen in Figure 24 the value has the lowest ranking and lowest position 16 in the lowest quadrant "C" and is the best candidate for Trimming. No components fall in the "D" quadrant.

The EAS next displays the Trimming Condition for the recommended or selected Trimmed component, e.g. the valve and the possible trimming variant, e.g. the piston. See Figure 25, where the related action "control" is also selected. The transfer of this action to another component, and in this example, "control" of the cylinder is transferred to the action between "piston" and "cylinder." This selection is accomplished by clicking on the upper button 20 and selecting "piston" from the menu bar 22. The trimming condition data was entered via unit 260 in Figure 1 that applies this data to unit 270 as described above. Unit 270 then modifies the original Functional Model data stored in unit 280 with the trimmed Model Data

stored in unit 280 is displayed via unit 285 and fed to the Problem Manager unit 230 and Report Generator 210. Figure 26 shows the trimmed functional model generated from the data stored in unit 280. Note the valve box is drawn in phantom because it was eliminated and no interaction exists between valve and cylinder. Note also that cylinder "control" has become an interaction between piston and cylinder. Cover and dust (harmful elements) also disappeared and are shown in phantom.

It is important to understand that the user and the EAS to this point in the session have not encountered any psychological inertia that may prevent innovative thinking. The object system has been dissected, evaluated and analyzed in it purest sense. The EAS, after analysis, has recommended to the user that the greatest value of redesign will result if the cylinder control action is transferred to the piston and the valve eliminated. How the piston itself can perform this added function becomes the problem statement to be managed by the EAS, Problem Manager.

The user now enters EAS Problem Manager that automatically generates a list of problems to be solved. Problem Manager is a tool that helps the user browse through all the problems associated with the trimmed functional model and to sort them based on value priority. Since the number of problems can be rather large, EAS calculates their significance and sorts them accordingly.

To start Problem Manager, the user clicks Problem Manager under Solution Tools in the Navigation window and the Table of Problems of Figure 34 is displayed. This table includes the problem Number assigned by Problem Manager, the significance generated by EAS of the problem, that is relative value if solved, the EAS generated group or type of problem solution

objective and the team member responsibility to be entered by the user if desired. The star 26 in the left hand column is placed by the EAS and means that this problem need not be solved if an element or function were trimmed. The user can highlight each problem number and the EAS lists the problem statement in box 28. Figure 34 lists the problem by problem number, but if the column heading "significance" is clicked upon, then the EAS will sort and list all table entries in order of "significance", not shown.

The EAS enables the user to search for problems associated with actions, components or supersystems of the functional model. For example, Figure 34 shows "by element name" selected and "air" entered and problem 1.1 highlighted. If the menu arrow 30 were clicked, other components and elements would be listed and any one of those selected and entered with the entered element problem data being displayed and highlighted in the table selection "by action name" can also be selected by the user. Problem data and evaluation take place in units 220, 200, and 230 of Figure 1 as described above.

The EAS also includes a Feature Transfer routine that enables the user to analyze the best feature or functions or alternate elements or alternate systems and compare those desirable alternate functions or elements to the function or element in the user's functional model function or element. This enables the user to analyze the alternate system to determine why specific elements yield better performance or parameters and identifies those features and operating principles that provide the better performance. With this understanding, the user then formulates problems in an attempt to transfer the better performing feature to the object system being designed or redesigned by the user.

The first Feature Transfer screen, Figure 35, is displayed when Feature Transfer is

selected from the "Tools" icon on the menu bar. The user enters the object or component to be analyzed such as piston 1, 2 and 3 as shown. One of these, e.g. piston 2, may be the piston from the current object system under evaluation by the EAS. The other pistons may be from other known pump models. User then enters the important parameters 1, 2, and 3 (or more), such as leakage resistance, etc., that user wants to improve in his/her pump. The arrow buttons in the objective column 30 enables user to indicate the increase or decrease objective for each parameter. Parameter units are entered by the user and the user enters the importance rank (10 = most important; 1 = least important) in the right column for each parameter. User clicks to the next screen, Figure 36, where user completes the table by entering numerical values for each parameter of each object. The Technological limit of a parameter is the value that the parameter could achieve if every modern technological achievement was used in designing the object. The Theoretical limit of a parameter is the best value that the parameter could achieve according to scientific theory. To finish the analysis and save the information to a report, the user clicks next button which brings up Figure 37.

The EAS Feature Transfer Routine analyzes the feature transfer data for piston 1, 2 and 3, integrates, displays the integrated results in Figure 37 by listing piston 1, 2 and 3 and assigning an EAS calculated relative performance index for each based upon a 100% total. The algorithm for Feature Transfer calculation is:

$$I = \frac{(K_i * P_i) * 100}{\sum (K_i * P_i)}$$

I - index;

K_i - parameter importance;

P_i - parameter value that is calculated as a percentage of sum of all parameter values.

Objects can be sorted by object number or index number by clicking the "Object" or "Index" box at the top of the column. User clicks next to get to the feature transfer recommendation screen, Figure 38. This screen provides short recommendations about how to improve the parameters of the chosen object using two different approaches: leading domain of technology and alternative system approach. The user clicks the name of the parameter to be improved, e.g. leakage, and EAS displays the short recommendations for the leading domain of technology and the Alternative approach. To get advanced recommendations for the alternative approach, the user clicks Advanced...near this recommendation.

If the user wants the EAS to undertake a more detailed analysis of feature transfer, then the "Advanced" button is selected to initiate an Alternative Approach subroutine and bring up Figure 39. On this screen the user can formulate several concepts using the alternative approach by first choosing the name of the concept from the Concept name list box. A short description of the alternative solution is entered in the field below the concept name list box. Express a technical reason why the alternative object has a better level of the considered parameter. See Figure 39. Next, a short description is entered in Concept Description of how to apply the alternative system approach to the considered object. See Figure 39. A series of dialog boxes is displayed to lead the user through the steps of analyzing a solution in an alternative system by clicking on Alternative system wizard box. To close the dialog box and save the information to a report to memory, click "OK". This will initiate a subroutine that presents four screens in sequence each asking a detailed question about the recommended object and listing the parameter to improve. For example, Figure 40 asks which element(s) is responsible for leakage. User enters the name of the initial or current object system element

"piston". To check the entry the user can note that if piston is trimmed, leakage is also deleted. There can be no leakage without a piston. Selecting next brings the Figure 41 display asking user to enter the element of the original object system that performs the function connected with leakage. Here the user entered "piston ring." Selecting next displays a screen that prompts user to enter the element(s) of the alternate system (piston 2 as recommended above) that performance the desired function.

Piston 2, in this example, used packing so user enters "packing" as the "element" in Figure 42. Selecting next displays the Figure 43 screen prompting entry of the specific "property" of the element "packing" in the alternative system (piston 2) to achieve a high level of "leakage" meaning high level of leakage control. User entered labyrinth in the feature box.

Whether or not feature transfer is used, the EAS unit 210 can generate a report by organizing and managing the information from the various and predetermined subroutines in the usual manner. Preferably a Report icon is displayed as part of the EAS navigation window and includes a "Generate" command that can be clicked to initiate the report. Parts of a report can be edited just as any word processing program can be edited.

The EAS hereof can be programmed by one of ordinary skill in the art using the following commercially available tools:

1. Borland C++, Development Suite
   for Windows 95 NT, 3.1
   and DOS V 5

2. NeoAccess
   Developers Tool Kit V 4

3. TGRID
   V 1.4 and 1.5
   Henry PICOT, Inc.

4. TE Developer Kit
   WIN 32 V 5.0
   Subsystems, Inc.

5. SPELL TIME V 2.0
   Subsystem, Inc.

It should be understood that the screens have cancel and finish buttons and allow user editing of displayed data function in the usual manner. If the user do not want to save the entered data to a related file in the memory unit, the user selects "cancel", and, if the user wants to save the entered data, the user selects "Finish".

An exemplary embodiment of the Process System Analysis module of the EAS will now be described with reference to Figures 2, 45, and 46 and the legend and glossary at the end of this specification. The user accesses this Process System Analysis module when it is desired to analyze, design or redesign a manufacturing or treatment process, method or technique. With reference to Figure 45 and the legend and glossary at the end of this specification, an EAS Process System Analysis session has five main Process System analysis stages termed Initial Process Data, Component Model, Process Functional Analysis, Operation Trimming, and Problem Statement. As the user develops the session, the user can return to and edit or modify any stage data at any time and the EAS will modify all stages of the entire project session accordingly.

The user starts a new session by accessing the EAS-Process System Analysis module.

The Process System Analysis prompts the user to enter the first stage "Initial Data." The user can enter initial data with use of the keyboard and/or mouse, such as project name, objectives, and objective ranking. During the Initial Data stage the user enters initial project data to the report unit 217 and problem manager 155. Report unit 217 functions to display elements of the final report on monitor 16 and enable the user to edit various parts of the report. Report generator 218 coordinates the project objectives and rank with model data unit 195 and processes the model data, problem data and trimmed model data into results, as described below, and generates the final report for display by report unit 217 and/or print report document 175.

During the Component Model stage, the user inputs data to Component graph unit 410. Unit 410 serves to display a graphic representation of the Component Model of the Process System under analysis. The user draws a symbol such as a box to represent each Component of the Process System model and a line between boxes to represent each Component added and its manufacturing sequence during the Process System. Boxes can be labeled on screen and the sequence number added. Color coding can be used to designate which Components result from process Operations or which are simply added to the Process System. See Figure 49 which is further described below.

During the Process Analysis stage, the user enters data to Operation graph unit 420 and Function table. Units 420 and 450 develop displays of the sequence of Operations (one or more) entered by user, that act on or produce each Component. The user also enters the identity and sequence of Functions that contribute to each Operation. As better seen in Figure 51, user clicks on Operations table 451 to display and enter the Component Operation and

related data used to produce the respective Component (see Figure 50). Next user enters the links between Operations on an Operations links graphic. As further described below, data can be entered or edited in unit 420 in graphics form and/or in unit 450 in table form. Function table unit also enables entry of a description of each Operation Function and the specification of the Functions, such as a Functions action, source or tool, target object or Component class of function, such as, useful or harmful and type of useful Function contributing to the Operation, such as productive, providing, or corrective.

The Process System Analysis further includes a Function Link Analysis unit 440 that receives data from unit 450 or directly from user input and unit 430 to analyze qualitative or quantitative values of detailed linking parameters between Functions and Operations. Each action can be represented on a parameter level with parameter behaviors on graphic diagrams displayed.

Model data unit 195 is primarily a data storage facility and obtains and feeds data to the many units generally shown in Figure 46.

As described below, the user calls up a link analysis unit 440 as part of the Functional Analysis Stage. This unit 440 enables the user to select for each link in the Operation Model a short description of the link, as well as its characteristic such as insufficient, normal, or excessive. This is done for each link in the Operation Model and the data stored in model data unit 195.

The user can, for any link, implement a more detailed link analysis that enables the user to detail the character of the action by means of comparing user entered actual values of an action with required values of the action. These values are also stored in model data unit 195.

This detailed link analysis enables four different types of data entry for the actual value and required value of an action parameter. These are Value, Time Dependency, Space Dependency, and Parameter Dependency. As described below, Parameter Value data can be represented either as qualitative relative ratio values or as quantitative values. For example, if the action link is "compress" between two Operations, the actual PSI and required PSI values can be entered in unit 440. In addition, the actual and desired tolerances can be entered such as ±2 psi and ±1 psi, respectively.

The Time Dependency data is entered to unit 440 by the user selecting the actual and desired parameter values over the desired duration of the action. Space Dependency data is entered to unit 440 by the user selecting the actual and required parameter value at various points in the space or distance through which the action occurs. Lastly, the user enters into unit 440 Parameter Dependency data for the actual and required link parameter as it relates to a separate other parameter in the object system functional model entered, i.e. named, by the user.

Although the above four detailed analyses are available, the user need not select them all and can simply not enter data which removes that analysis from consideration by the EAS-Process System Analysis.

All user entered Link Analysis and detailed Link Analysis data are stored to the model data Unit 195.

A Process System usually includes harmful operation Functions and useful operation Functions which are not optimally fulfilled. Every disadvantage in a Process System presents a problem that should be solved. Also, distribution of process benefits among Operations are usually not uniform. Some Operations contribute greatly and others are insignificant to the

process objective.

In addition, each Function within each Operation had data entered, inter alia, including its action, element type and performance. The type of Function includes harmful and useful, and the useful Functions can be further classified as Productive, Corrective, and Providing. See the Glossary for a further definition of each type. Although the user selects the Function type for each Function of each Operation, the PSA also stores a value or score associated with a specified Function type designation. For example, Productive is given a 3 value, Providing 15 given a 2 value, Corrective is given a 1 value and Harmful is given a zero value. These values are also stored in model data unit 195 and used in subsequent evaluation algorithms.

Once satisfied with data entry, the user initiates the Operation Trimming stage. This routine enables the user to evaluate and determine which Functions and/or Operations, if trimmed would yield the greatest value toward the project objective.

The PSA uses an operation evaluation algorithm to choose the recommended order in which to trim operations. The algorithm uses standardized values of the problem rank (P), function rank (F), and cost (C) as entered by the user at unit 245. The evaluation unit 225 then generates a graph to illustrate its calculations.

Model data unit 195 communicates continuously with F, P, C Evaluation unit 225 which includes internal processing routines that apply the model data from unit 195 to the following default criterion algorithm:

$$\frac{F^2}{P+C} = \text{Trimming Factor}$$

where

F = function rank of Operation

P = problem rank of Operation

C = cost of Operation

Unit 225 then calculates the highest to lowest scores for each Operation and feeds this data to units 245, 195, and 235. Unit 245 plots and displays the operations on the graph and places the Operation with the highest functional rank at the top of the vertical axis. The functional ranks of all the other operations are calculated as a percentage of this maximum rank. The procedure is the same for the horizontal axis, which shows the combination of problem rank and cost. From geometrical point of view the criterion formula, preferably, describes a set of parabolas or other lines. The least value of criterion means the narrowest parabola. PSA trimming recommendation for each Operation depends on where it falls on the graph. In the illustration above, the PSA would recommend trimming the Operation with the lowest function rank and highest problem rank and cost. Of course, the user can always quickly and visually analyze the information presented by PSA and make his/her own decision.

If desired, the PSA enables the user to enter a customized trimming parameter or algorithm in unit 245. If user selects this option, unit 245 presents a dialog box displaying the following:

$$K = \frac{\sum (kB)}{\sum (kW)}$$

K = user criterion

B = standardized value of objectives that should be increased

W = standardized value of objectives that should be decreased

k = value of importance of each object Operation

User selects which Operation(s) should be applied to this formula to thereby customize the trimming criterion.

Unit 245 then feeds unit 225 for modifying the output thereof which is fed to unit 235.

If user enters no data to unit 245, the unit 225 output is fed unmodified to unit 235 and unit 255 in which the data is processed to search for the priority of Operation trimming candidates.

Unit 265, in response to unit 245 data, presents (displays) a set of rules for trimming conditions for the trimming candidate Operations generated by unit 255. For example, one preferred set of rules can be:

Productive function:.

Function can be trimmed if:

1. the function is performed during another operation;
2. there is no object of function;
3. there is no need to perform function;
4. the function is performed during the new operation.

Providing function:.

Function can be trimmed if:

1. there are no "provided" operations (functions);
2. the function is performed during another operation;
3. there is no need to perform function;
4. the function is performed during the new operation.

Corrective function:

Function can be trimmed if:

1. there are no corrected operations (functions);
2. the function is performed during another operation;
3. the corrected operations do not create defect;
4. defect does not impede design work;
5. there is no object of function;
6. the function is performed during the new operation.

Each trimming conditions requires a formulated problem.

Unit 255 data is also fed to unit 275 where the trimming condition is evaluated. User can interact and modify the Process System Analysis object structure through unit 265.

One exemplary analysis of a process system will now be described with reference to Figures 2, 45-66. In this example, the user desires to analyze and improve a manufacturing process for producing an assembled shaft and gear in less time with less energy than the company's existing process.

User accesses the PSA and enters the Initial Data stage. The PSA displays the screen of Figure 47 and prompts user to enter the Project Name, Process identity and present Process description. One or more Objectives must be entered. In this example, the user is presented with an Objectives table in which the user can click on the left most arrow to bring up a menu that can include a plurality of suggested objectives such as:

Energy consumption
Equipment cost
Labor expenditures
Losses of product material
Maintenance
Reliability
Safety conditions
Used area
Operation time

As seen in Figure 47, user selected Energy consumption in Row 1 and Operation time in Row 2 and selected Down for both of the desired conditions. User also entered the energy and each of the right hand Importance slide based on a 1-10 scale.

By clicking on the Team icon, the screen in Figure 48 appears where the user can enter all team members and related data and other project information that will appear on the report. This completes the Initial Data stage although the PSA could include additional data entry in this stage if desired.

User initiates the Component Model stage by clicking on the Components icon at the screen left. The PSA presents the screen (initially blank) of Figure 49. User then draws box 1 and labels it "shaft" and box 2 and labels it "Gear". User then draws box 3 and labels it "Assembly Unit" and draws an arrow line from box 1 to box 3 and a second arrow line from box 2 to box 3, generally as shown. It will be understood that this example only involves the assembly of two units, however, the PSA has the capacity to analyze large complex systems that include many components, subassemblies and assemblies that could be drawn in Figure 49.

Next the user clicks on the Operation icon to bring up the table shown in Figure 50 in which the shaft, gear and assembly unit already appear on the left side in response to data entered in the previous screen. Figure 50 table prompts user to enter one or more operation steps currently used to make the highlighted component. In this example, user entered in the first column, in proper numbered sequence, Cutting, Heat Treatment and Finishing. The PSA automatically designates the next columns the same as the Parameter objective row headings from initial data screen Figure 47, i.e., Energy Consumption (kw) and Operation Time (min.)

and enables user to enter the present values for each operation step. Similar data (not shown) is entered for the other component (Gear) in the assembly and for the Assembly Unit which would include steps, energy and time necessary to assemble the components as a unit.

Next, user clicks on Function tab of Figure 50 in response to which the PSA displays the screen of Figure 51. Here the PSA enables user to break down broad operation steps into more detailed specific actions, the specific tools used to perform action, and the element of the component acted upon. As mentioned above, the action is ranked into one of 4 categories (Productive; Providing; Corrective; and Harmful) and its performance effect or value indicated.

As seen in Figure 51A the upper part includes the three steps in forming the shaft: 1.1 Cutting, 1.2 Heating and 1.3 Finishing. These operation steps also appear in the table in the lower portion with the columns headed as mentioned above. The user highlights the component, i.e. Shaft, that brings up the two tables depicted but without any data other than the three operation steps Cutting, Heat Treatment and Finishing as described above. Next user clicks on the "tool" arrow in row 1 of 1.1 and is presented with a list of tools. User selected "spindle" which appears in row 1. Next, user enters the action "rotate" in the next column and selects "shaft" as the element receiving the action ort acted upon by the spindle. Next the action is ranked by type. In this case, user entered Providing for the spindle in which case the PSA stores a "3" rank level for the spindle. Next the user enters the performance level of the tool/action which for the spindle is set at zero meaning optimal average performance, neither above (+) nor below (-) optimal.

As seen in Cutting 1.1 row 2, user enters Cutter – Removes – metal as a productive action with a mass metal removal value of 4.0.

User repeats entry of associated data for each action of each operation step, selects the specific tool that effects the action, designates the component element to which the action is directed, designates the type of action for the ranking value to be stored and enters the quantitative or qualitative value of the tool/action performance. As this data is entered, the PSA also displays the pertinent data in the upper chart of Figures 51A and 51B and stores the same in respective units of Figure 46.

With the data entered in the screen of Figure 51B, the user can click on any function such as the symbol in the "Type" column. The PSA responds by displaying the screen in Figure 52 for the function 1.1.1 or Spindle Rotate Shaft with Providing checked or highlighted. The PSA displays a graphic to the right which shows the object of the function (shaft) and the operation steps and functions entered in Figure 51B in hierarchical fashion.

User then selects those displayed operations and functions that are associated with the function "spindle rotates shaft". In this example, user clicked on the boxes labeled Cutting 1.1 and Cutter Remove Metal 1.1.2 because the function directly or indirectly provides the cutting action and the ability for the cutter to remove metal. The user understands that the cutter alone can not remove metal (in the present system) unless the spindle rotates the shaft under the cutter. Since the function "spindle rotates shaft" is not associated with Heat Treatment or Finishing, user checked no other box in Figure 52. The user, when satisfied, clicks on "OK" and the screen of Figure 51A re-appears with a new indicator, such as arrow 455, which represents a logic link between two respective functions. The user can now click on Function 1.1.2 Cutter Remove Metal and the screen of Figure 53 appears. If desired, a "Next" button (not shown) can be provided in Figure 52 screen which, when selected, immediately causes

screen Figure 53 to appear. Alternatively, screen Figure 53 can appear when the "OK" button is selected in screen Figure 52. Whenever an "OK" button is selected, the user entered data is stored or processed by the PSA as described above.

Referring to screen Figure 53, the PSA highlights Productive for the function Cutter Removes Metal. No box on the right side can be checked because this function is the ultimate objective of the operation step, i.e. the Productive characteristic was designated for this function as described above.

The user then steps through the other functions displayed in screen Figure 51A employing the same method as described above. Upon displaying the function Air Oxidize Shaft (1.2.3), screen Figure 54 is displayed with Harmful type highlighted, e.g. appearing in red. The user can select no box under Heat Treatment because the action is designated harmful. User simply clicks "OK" and moves on.

Upon the user selecting function Grindstone Remove Slag (1.3.2) on screen Figure 51, the PSA displays screen Figure 55 with corrective type highlighted. Above the right graphic appears "Corrects What?" and the hierarchical functions of the process.

User clicks on Air Oxidize Shaft (Figure 55) as the object of the corrective action of the function Grindstone Remove Slag. The PSA also clicks Heat Treatment operation step as receiving the correction.

Once the user enters appropriate data of the type described for all functions of all operation steps, the other logic link arrows are generated and displayed by the PSA as shown at the top portion of Figure 51. At any time, the user can initiate the Link Analysis substage by clicking on the right most icon 456 for a specific function in Figure 51.

In response. the PSA displays a Link Analysis screen for each function of each operation selected. The PSA prompts user to enter in graphic form the actual and required behavior of a user designated parameter through a time, space, and/or other parameter dependency. For example, Figure 56 shows the Link Analysis screen for the function Inductor Heats Shaft (1.2.2). User designated "temperature" as a "useful" action and checked "time" as the dependency. The PSA displayed two graphics labeled "Actual" and "Required" behavior with all points (small circles) lying on the time axis. User then uses the cursor to move points (shown as small circles) to estimated vertical positions above the "time" axis to display and enter data of the actual and desired temperature/time curves. The PSA also enables entry of the significance factor for the temperature behavior and the acceptable deviation on a slide bar. The difference between the under-curve areas of the two graphs is calculated by PSA and also disp0layed, for example 8.0 in Figure 56.

Next user clicks on "significance" appearing on screen Figure 56. This causes display of screen Figure 57 where user is prompted to enter the effect on each objective of the influence on the process if the required dependency could be achieved. For example, the temperature/ time dependency would have no effect on the "operation time" objective if the actual temperature/time dependency were made to be the same as the required one. Accordingly, user leaves the indicator on "no" (meaning "none") for the "Operation Time" row of screen Figure 57. However, since less energy is needed for the "required" than the "actual" behavior in Screen Figure 56, user slides the marker to the left, i.e., "decreases". Difference is the average of the differences of the corresponding points of the two curves of Figure 56, which in this example equals "+8.0".

With the markers set, the PSA displays the values. Note the scale reads from, in this example, zero to 2 in the direction of the objective ("Down"). If an objective were shown having an "Up" designation, the zero for it would be on the left and the 2 on the right of the marker scale.

The PSA acquires the readings of all rows (in this example, two rows) and calculates the significance which, for screen Figure 57, is 6.0 using the algorithm as shown thereon. Note the importance factor had been entered by user during the Initial Data stage, see right side of Figure 47. User clicks on "OK" and the PSA displays the "6.0" in the significance box in Figure 56. Then clicking on "OK" in Screen Figure 56 completes the link analysis and data entry for Inductor Heats Shaft and, in response, the PSA displays the same screens for the next stored Function. The link analysis method is repeated for all stored Functions.

Once the Link Analysis stage is completed to user's satisfaction, user moves to the Operation Trimming Stage by clicking on the Trimming Icon of any previous screen. The goal of this stage is to rank and analyze the various operations and functions, analyze the possible elimination or transfer of functions against a stored set of rules set forth above and display certain recommendations of elimination or transfer in order of importance to achieving stored objectives.

Upon entering Trimming Stage, the PSA first displays an Operation Evaluation Screen Figure 58 which prompts each team member to rank each operation on a 10-1 scale for:

Function Rank: Importance of each Function to the process = 10

Problem Rank: Largest Problem to implement = 10

Cost: Actual or allocated cost in Dollars for the operation.

As seen in Figures 58, 59A and 59B, each team member entered his/her estimated function and problem ranks. If desired, the system can be configured so that each team member can see displayed only the ranking data he/she entered The PSA calculates the average and displays the results in the right hand columns of the screen. Each team member views the results, speaks with the other team members and makes modifications to his own evaluation as desired. In this case, the PSA will process the average of the various evaluations. When any team member presses the "consensus" button, data that team entered is entered and for all team member data.

User next clicks on the "next" icon of Figure 59B causing the PSA to display the screen Figure 60. The purpose of this screen is to display a number of Operations in possible (PSA recommended) trimming order based on the Trimming Factor resulting from processing the data with the algorithm as shown in Figures 60 and 61, Function Rank (e.g., as a percentage of 100%) and Problem Rank. The Trimming Factor value for each operation defines a specific parabolic curve. The smaller the area under the curve, the greater the value will result from trimming. In the present example, the PSA recommends Trimming or improving Heat Treatment (1.2) to yield the greatest value toward the entered project objectives. The PSA recommends improving or trimming Finishing to achieve the next best value and so on. In essence, the PSA, in this screen, presents a recommended list, in rank order of value, of operations to be trimmed or improved. PSA generates this list by applying the algorithm appearing in screen Figure 61, which user accesses by clicking n the "set criterion" button in Figure 60. In the event user does not wish to use the default algorithm, user clicks on "User's criterion" and enters user's own algorithm generally as shown. In any event, the PSA calculates

the trimming factor using the user selected or entered algorithm and displays the results preferably in graphic and/or table form as described above and as shown in Figure 60. Obviously, other forms of ranking display can be used instead of the specific ones shown in this exemplary embodiment.

Once satisfied, user clicks on "Next" to enter the Trimming Conditions routine in which the PSA will evaluate and recommend possible trimming conditions for overall process improvement. It is recommended the reader also refer to Figures 51A and 51B when reading the following. The Trimming Routine has access to previous stage data and also stores a set of internal rules for effecting the trimming or transfer recommendations. Specifically, in one exemplary example, those rules included the following:

If user chooses trimming condition:

The function to <action1 object1> performed during the operation <List of operations>.

This means that function <action1 object1> should be transferred to one of the operations from the <List of operations>.

In the present example shown in Figure 51A and Figure 60,

action 1 = heat, and

object 1 = shaft

The PSA Trimming Routine automatically lists (parses) the stored Operations in accordance with the following ordered rules:

1. operation contains function with name <action1 object1>
2. operation contains function with name <action1 object1>
3. adjoining previous operation

4. adjoining subsequent operation

If several operations meet the requirement of one of the conditions the PSA selects the next condition.

The PSA also analyzes logic links (Corrective, Providing) between functions and in accordance with this analysis displays to the user additional trimming conditions.

5. If function <action2 object2> provides function <action1 object1> and function <action1 object1> is transferred to another operation then PSA generate the following trimming conditions for function <action2 object2>

- Trim the operation/function <action2 object2>
- The function action2 provides function <action1 object1>

In the present example shown in Figures 51A and 60:

action2 = support

object2 = shaft

Note in Figure 51A, "support shaft" provides "heat shaft", thus "shaft" is object1 and object2 in the present example.

6. If function <action2 object2> corrects function <action1 object1> and function <action1 object1> is transferred to another operation then PSA generates the following trimming conditions for function <action2 object2>

- Trim the operation/function <action2 object2>
- The function action2 corrects function <action1 object1>

Thus, as seen below, application of Rule 6 in the present example can enable trimming of "support shaft" if the object 1 "shaft" is transferred to another operation because there is no

need to "provide" in an operation if the provided object is transferred (or eliminated).

With reference to the above logic rules, when user selects "next" in Figure 60, the PSA enables a transfer action evaluation routine and Figure 62 appears with the Operation and Function with the highest candidate rating from Figure 60. In the present PSA example, best candidate for trimming is Heat Treatment - heat shaft. The PSA displays in rank order the four trimming/transfer possibilities with the best (first on list) possibility or condition automatically selected as a default, which is the PSA best recommendation. User can override the default and select what user considers the most beneficial possibility by clicking on one of the other listed possibilities, e.g. "There is no object 'shaft' ", if desired. In addition, the PSA shows the Operation -Function block diagram graphic with the default or selected block crossed out, in this example "heat shaft".

Figure 62 also displays the graphic Operation, "Cutting", to which Operation the PSA recommends "heat shaft" be transferred. An arrow showing the direction of the transfer also renders clear information for the trimming or transfer recommended.

It should be understood that the user can simply and quickly evaluate various alternatives by clicking on alternate buttons to see and evaluate the modified process automatically displayed in the PSA. Thus, the PSA greatly enhances the user's ability to analyze the merits or disadvantages of possible process modification.

If agreeable, the user selects "next" to enable a logic link and related Function analysis and, in response, the PSA automatically displays Figure 63A wherein the PSA recommends the elimination of "support shaft" function because, as seen in Figure 51A, its purpose was a Providing Function to "heat shaft" which user agreed to transfer to a different operation, i.e..

"Cutting".

Other possible trimming or transfer logic link conditions are also listed to enable user to override the PSA default (best) recommendation. Note button 271 for introducing alternate logic links and arrow 272 for introducing alternate trimmed functions.

When satisfied, user clicks "next" and PSA displays the next important recommendation, i.e.. "remove slag" from the Finishing Operation. The PSA stored data indicating that "remove slag" was a corrective action because of the Harmful "oxidize shaft" function during the Heat Treatment Operation. See Figure 51A. Since "heat shaft" is transferred the PSA recommends dropping "remove slag" in Figure 63B.

When the user clicks "next" the PSA displays its recommendation to trim the "providing" action by "rotate shaft" to "remove slag" because "remove slag" had been trimmed.

Because there are no further possible trimming or transferring actions, when the user clicks "next" in Figure 64, the PSA displays Figure 65, the overall trimmed process block diagram, similar Figure 51A, with the trimmed, and transferred functions and actions crossed out or modified or removed or shown under different Operations. Figure 65 is generated from data stored for Figures 51A and 51B and Figures 62A through 64 and confirmed when user clicks "next" during the trimming condition routine. User with Figure 65 can now see and understand what the new trimmed process can look like. Although Figure 65 can not be edited, any of the data in prior screens can be changed at any time to affect the data shown in Figure 65.

The user next can select Problem Manager displayed in Figure 65. The PSA displays Figure 66 which lists the problems to be solved in achieving a better, modified process. The

PSA clearly lays out the problems on the right side of Figure 66. On the left specific actions are listed along with the Problem Significance of each action generated by PSA from stored input data described above. Note the action with the highest significance (value) is "heat shaft transfer" with 83.0 compared to the others in the present example.

Accordingly, PSA advises user that solving the problem of how to transfer "heat shaft" to the Cutting operation will contribute the most, by far, toward the process redesign objectives of the entire project.

It will be understood by engineers and process designers that a computer based EAS-PSA provides a powerful tool enabling the user to undertake extensive, automatic process design, logic based analyses of a subject process and to obtain PSA recommendations of the most to the least significant design changes related to process modifications and to obtain a ranking list of the technical problems to be solved that will yield the greatest to the least benefits to the user and process design. It should also be understood that the design, layout, graphics, colors, and word choice appearing in screen shots disclosed in this application are exemplary and not limiting on the concepts and functions of the present invention. Architectural layout and flow charts are also exemplary of one embodiment of the present invention, and certain herein disclosed routines and software functions can be associated with various stages and software units for the convenience of the programmer as desired. It will be understood that various modifications and changes can be made to the herein disclosed examples without departing from the spirit and scope of the present invention.

GLOSSARY FOR EAS-PSA (Process System Analysis)

PROCESS:

Manufacturing Process: a model of an engineering system which reflects the nature and sequence of action undertaken on the main functions object of the engineering system and on the components of the object's supersystem.

Operation: Part of the technological process: a sequence of actions undertaken on the main function object of a given system and on the components of that object's supersystem.

FUNCTIONS:

Function: action of a material object that changes the parameters of another material object.

Carrier of the Function: an object that performs the function

Object of the Function: a material object that the action of the considered function is applied to.

Function Type: Characteristic of a function that reflects specific changes introduced into the object through fulfillment of the function.

Function of Operation: a function executed within the framework of a given operation.

Useful Function: a function that satisfies the requirements of the user of the function carrier.

Productive Function: a useful function that permanently changes the parameter(s) of the object. This change will exist partially or fully in the final state of the object or will bring object's parameters closer to that object's desired final state. (Example: cut shaft to length 12".)

Providing Function: a useful function that temporarily changes the parameter(s) of the object. This parameter change enables or facilitates subsequent or concurrent useful functions or operations. The temporary changes produced by providing functions are reversed by corrective functions (Example: heat an object to 100°, allow to cool to room temperature).

Corrective Function: a useful function that changes the parameter(s) of the object to eliminate unwanted object characteristics. This parameter change may reverse the changes of a providing function, reverse the changes of an excessive productive function, or eliminate/reduce unwanted results of a harmful function. (Example: file a cut metal edge to remove burs).

Harmful Function: a function that worsens the parameter(s) and/or performance of an object.

Parameter: descriptions of properties in terms of measure or quality or characteristic.

ACTIONS:

Useful Action: an action performing a useful function.

Harmful Action: an action performing a harmful function.

INTENSITY OF ACTIONS:

Normal Intensity: a situation when the actual intensity coincides with the required one.

Excessive Intensity: a situation when the actual intensity exceeds the required one.

Insufficient Intensity: a situation when the required intensity exceeds the actual one.

PARAMETERS OF ACTIONS (VALUES AND DEPENDENCIES):

Useful:

Actual Value: the value of a parameter at a point in its life cycle.

Required Value: a value that a parameter should have for optimal performance of its corresponding function(s).

Actual Dependency: a dependency that the parameter has at a point in its life cycle.

Required Dependency: a dependency that a parameter should have for optimal performance of its corresponding function(s).

Acceptable Deviation: indicates the acceptable limits of the required value.

Harmful:

Actual Value: value that the parameter has during the object life stage.

Acceptable Value: Value that provides an acceptable level of damage for the object.

Ideal value: value that provides absence of damage to the object.

Acceptable Deviation: the variance allowed from the required or acceptable value of a parameter.

TRIMMING:

Trimming: a method of improving manufacturing process based upon the elimination of operations and the redistribution of their useful functions. The result of this is a simpler, more cost-effective process which performs as well (or better) than the original.

Trimming Conditions: the various options available for redistributing useful functions.

Goals of Trimming: the problem to be solved to realize the chosen trimming conditions.

WE CLAIM:

Claim 1. A digital computer system having a computer readable storage medium comprising a process system analysis module for analyzing a process system, said process analysis system module comprising:

a component model unit responsive to user entered component model data for storing said component model data and generating on the computer screen a visual representation of a component model of the process system including said functional model components, operations that produce each component, and functions that form each operation,

each function comprising an element or tool that performs an action and an element or tool that receives the action,

a process analysis unit including a link analysis routine which is responsive to user entry to store and display logic links between functions of each operation and between functions of each operation and functions of other operations and to store and display link data representing one of at least three types for each link,

a trimming unit comprising a stored set of rules, analyzing component model data and link data against said rules for generating recommendations for the elimination or transfer of some of said functions and designation of the relative importance to the modification of the process system of each recommendation, and wherein

said process system analysis module displays said representation of said some of said functions and representations of said designation.

Claim 2 . A digital computer system as set forth in Claim 1 wherein

said component model data includes a sequence of said functions in each said operation, at least one of cost, energy consumption, actuation time of each function.

Claim 3. A digital computer system as set forth in Claim 1 wherein said link data includes four types including Harmful, Providing, Corrective and Productive.

Claim 4. A digital computer system as set forth in Claim 1 wherein said link data includes function performance data.

Claim 5. A digital computer system as set forth in Claim 1 wherein said link data includes time, space, and parameter dependencies.

Claim 6. A digital computer system as set forth in Claim 5 wherein said link data includes a quantitative representation of the significance of each function.

Claim 7. A digital computer system as set forth in Claim 5 wherein said component model data includes a quantitative representation of the actual and required behavior for each parameter of each function.

Claim 8. A digital computer system as set forth in Claim 1 wherein said model data includes for each function, function rank, problem rank, and cost data.

Claim 9. A digital computer system as set forth in Claim 1 wherein said process analysis unit includes (i) a trimming/transfer set criterion routine including a trimming/transfer algorithm and (ii) an integrated operation evaluation routine for determining and displaying in table form or graphically the priority order of each function of each operation as a candidate for transfer or elimination and in response to the function rank, problem rank, and cost of the trimming factor of each function

Claim 10. A digital computer system as set forth in Claim 1 wherein said trimming unit displays portions of said component model displaying the operation from which a function is recommended or selected for transfer and the operation to which a function is transferred and representations showing the transfer.

Claim 11. A digital computer system as set forth in Claim 1 wherein said trimming unit displays portions of said component model displaying one or more trimming conditions in rank order of significance to process improvement which trimming conditions can be selected selectively by the user.

Claim 12. A digital computer system as set forth in Claim 1 wherein said trimming unit displays portions of said component model displaying the operation from which a function is recommended or selected for elimination and the operation and function which is effected by said elimination.

Claim 13. A digital computer system as set forth in Claim 1 wherein said trimming unit displays portions of said component model displaying the operations and functions between which a link is recommended or selected for elimination.

Claim 14. A digital computer system as set forth in Claim 1 wherein the trimming unit generates representations of a modified component model showing transferred and eliminated operations, functions, and links.

Claim 15. A digital computer system as set forth in Claim 1 wherein said process analysis system further comprises a problem manager unit for generating representations of a list of problems to be solved with indications of the most significant to least significant function transfer or elimination problems which if solved would yield the most to the least improvement to the process system.

Claim 16. In a digital computer system, the method of analyzing a process system comprising:

storing user entered component model data,

using at least a portion of stored component model data for generating and displaying on the computer monitor a visual representation of a component model of the process system including functional model components, operations that produce each component, and functions that form each operation, each function comprising an element or tool that performs an action and an element or tool that receives the action,

storing and displaying logic links between functions of each operation and between

functions of each operation and functions of other operations, and storing and displaying link data representing one of at least three types for each link,

storing a set of trimming rules,

analyzing component model data and link data against said rules and generating recommendations for the elimination or transfer to other operations of some of said functions and designating the relative importance to the modification of the process system of each recommendation, and

displaying said representation of said some of said functions and representations of said importance designations.

Claim 17. In a digital computer, a method according to Claim 16 wherein said component model data and said component model includes a sequence of said functions in each said operation, and at least one of cost, energy consumption, actuation time of each function.

Claim 18. In a digital computer, a method according to Claim 16 wherein said link data includes four types including Harmful, Providing, Corrective and Productive.

Claim 19. In a digital computer, a method according to Claim 16 wherein said link data includes function performance data.

Claim 20. In a digital computer, a method according to Claim 16 wherein said link data includes time, space, and parameter dependencies.

Claim 21. In a digital computer, a method according to Claim 20 wherein said link data includes a quantitative representation of the significance of each function.

Claim 22. In a digital computer, a method according to Claim 20 wherein said component model data includes a quantitative representation of the actual and required behavior for each parameter of each function.

Claim 23. In a digital computer, a method according to Claim 16 wherein said component model data includes for each function, function rank, problem rank, and cost data.

Claim 24. In a digital computer, a method according to Claim 16 further comprising

storing function rank, problem rank, and cost data for each function,

storing a trimming/transfer algorithm for generating a trimming factor using the stored function rank, problem rank, and cost data, and

determining and displaying in table form or graphically the trimming factor priority order of each function of each operation as a candidate for transfer or elimination.

Claim 25. In a digital computer, a method according to Claim 16 further comprising displaying portions of said component model showing the operation from which a function is recommended or selected for transfer and the operation to which a function is transferred and representations showing the transfer.

Claim 26. In a digital computer, a method according to Claim 16 further comprising displaying portions of said component model showing one or more trimming conditions in rank order of significance to process improvement with trimming conditions can be selected selectively by the user.

Claim 27. In a digital computer, a method according to Claim 16 further comprising displaying portions of said component model showing the operation from which a function is recommended or selected for elimination and the operation and function which is effected by said elimination.

Claim 28. In a digital computer, a method according to Claim 16 further comprising displaying portions of said component model showing the operations and functions between which a link is recommended or selected for elimination.

Claim 29. In a digital computer, a method according to Claim 16 further comprising generating representations of a modified component model showing transferred and eliminated operations, functions, and links.

Claim 30. In a digital computer, a method according to Claim 16 further comprising generating and displaying representations of a list of problems to be solved with indications of the most significant to least significant function transfer or elimination problems which if solved would yield the most to the least improvement to the process system.

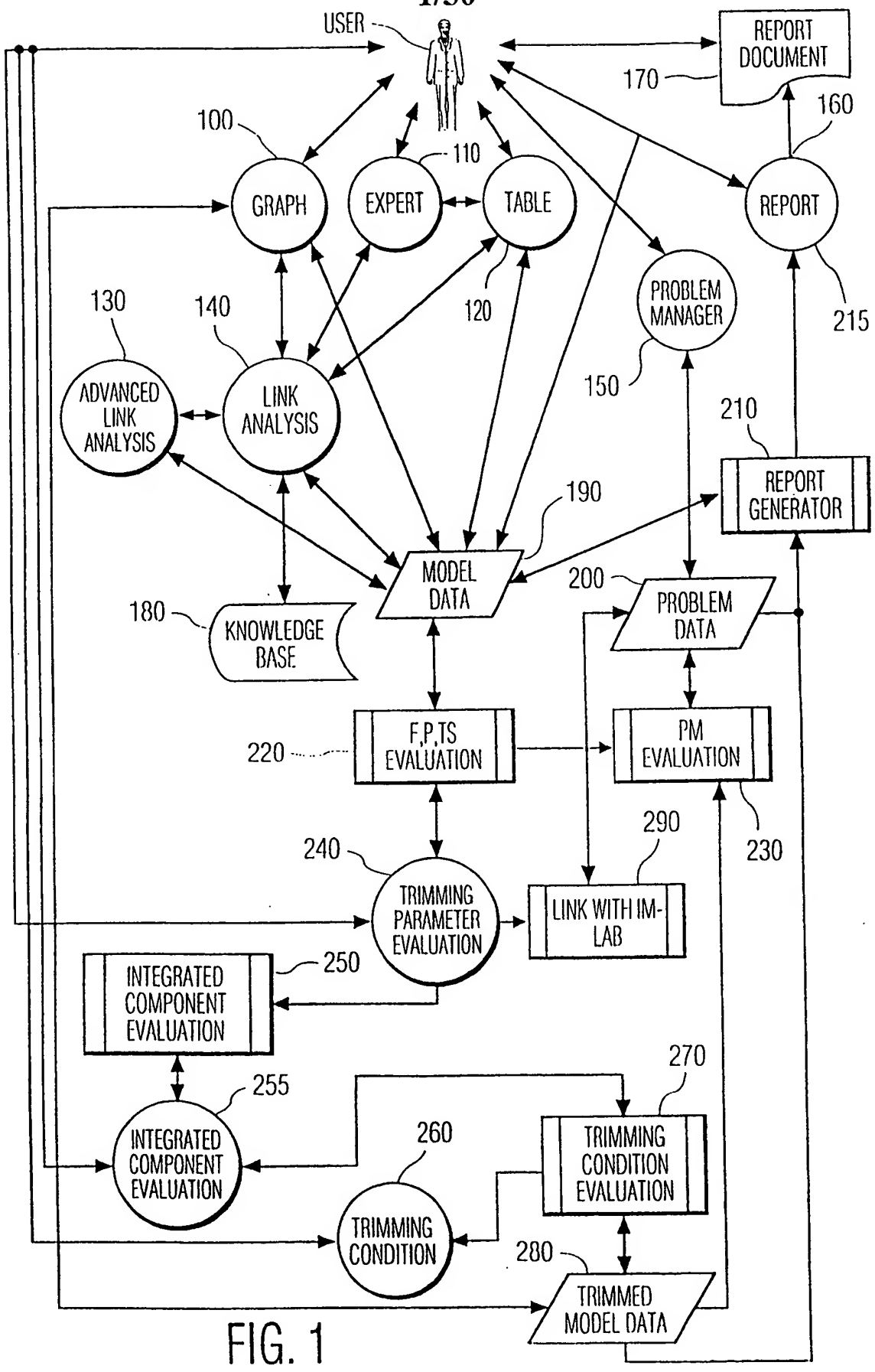

USER
REPORT DOCUMENT
170
160
100
110
GRAPH
EXPERT
TABLE
REPORT
PROBLEM MANAGER
130
140
120
215
ADVANCED LINK ANALYSIS
LINK ANALYSIS
150
210
REPORT GENERATOR
190
MODEL DATA
200
PROBLEM DATA
180
KNOWLEDGE BASE
F,P,TS EVALUATION
220
PM EVALUATION
290
230
240
TRIMMING PARAMETER EVALUATION
LINK WITH IM-LAB
INTEGRATED COMPONENT EVALUATION
250
270
255
INTEGRATED COMPONENT EVALUATION
260
TRIMMING CONDITION EVALUATION
TRIMMING CONDITION
280
TRIMMED MODEL DATA

FIG. 1

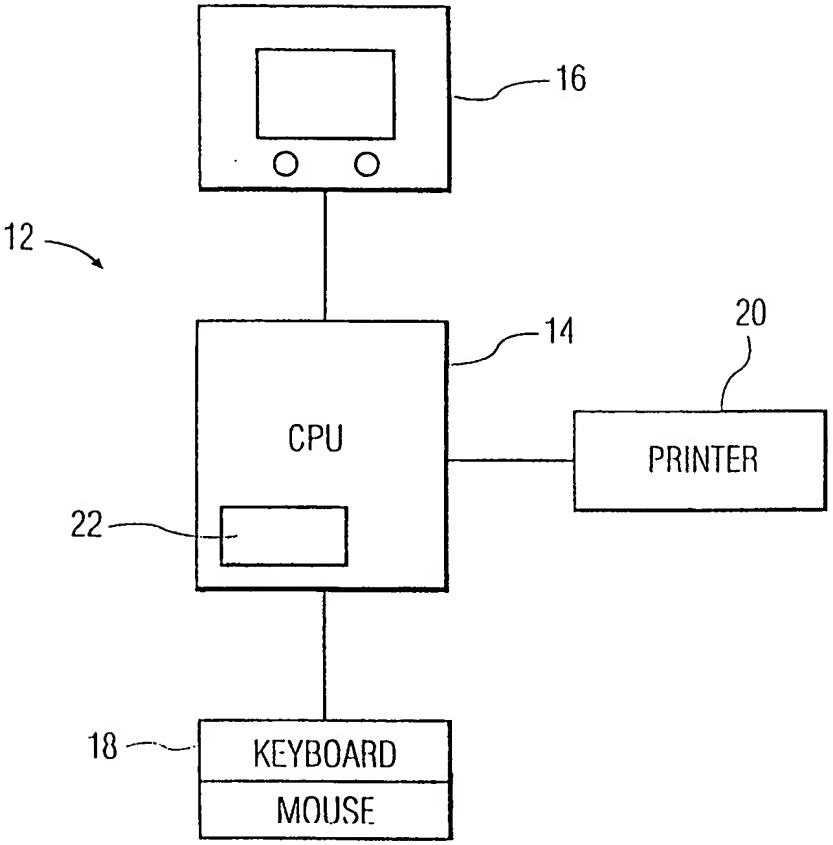

16
12
14
20
CPU
PRINTER
22
18
KEYBOARD
MOUSE

FIG. 2

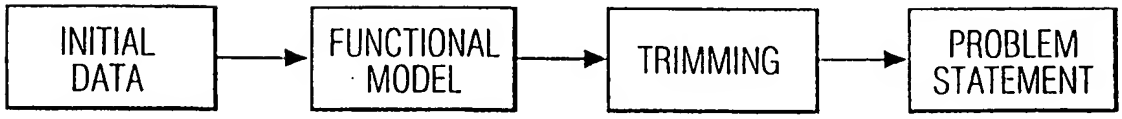

INITIAL DATA
FUNCTIONAL MODEL
TRIMMING
PROBLEM STATEMENT

FIG. 3

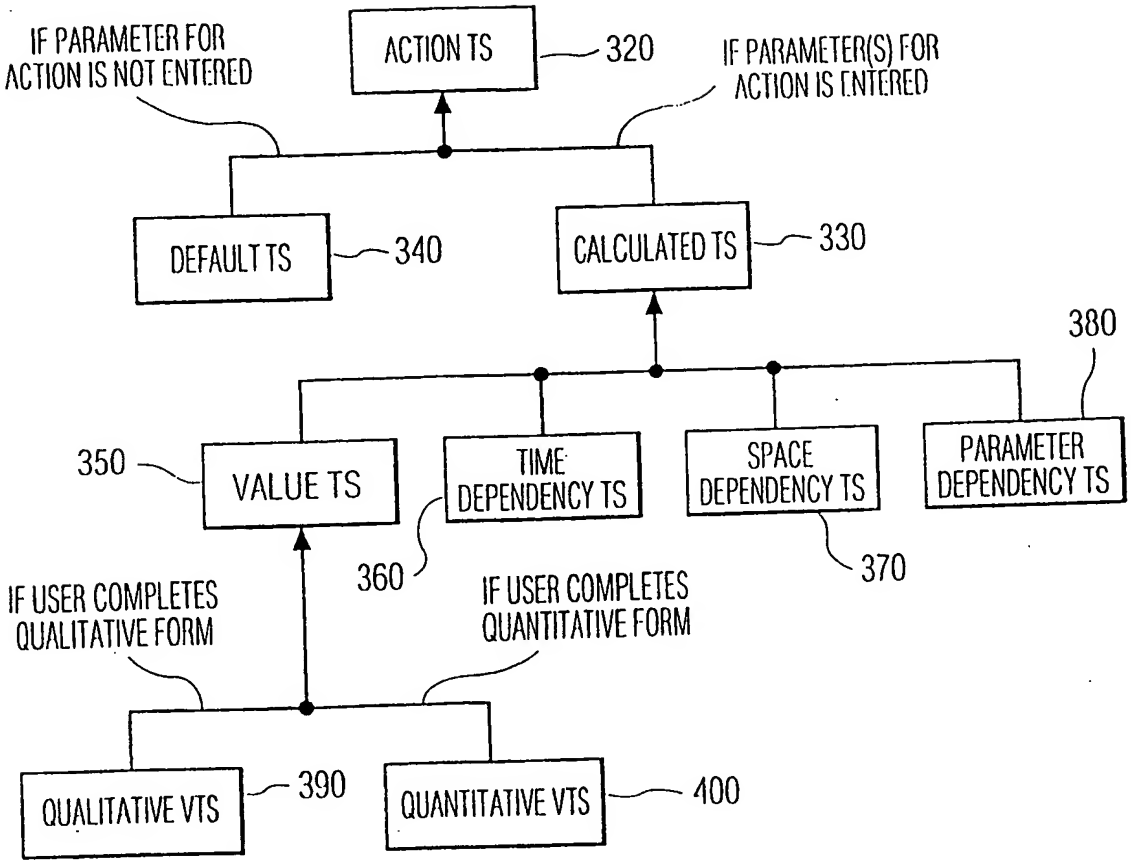

IF PARAMETER FOR ACTION IS NOT ENTERED
ACTION TS
320
IF PARAMETER(S) FOR ACTION IS ENTERED
DEFAULT TS
340
CALCULATED TS
330
380
350
VALUE TS
TIME DEPENDENCY TS
SPACE DEPENDENCY TS
PARAMETER DEPENDENCY TS
360
370
IF USER COMPLETES QUALITATIVE FORM
IF USER COMPLETES QUANTITATIVE FORM
QUALITATIVE VTS
390
QUANTITATIVE VTS
400

FIG. 4

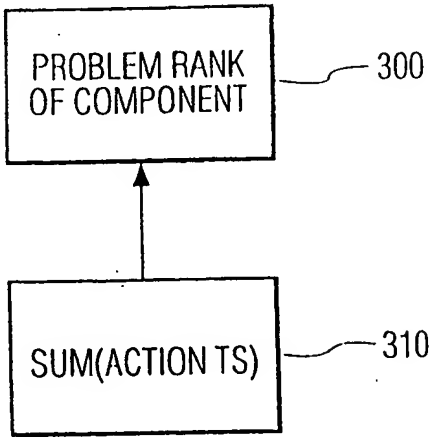

PROBLEM RANK OF COMPONENT
300
SUM(ACTION TS)
310

FIG. 5

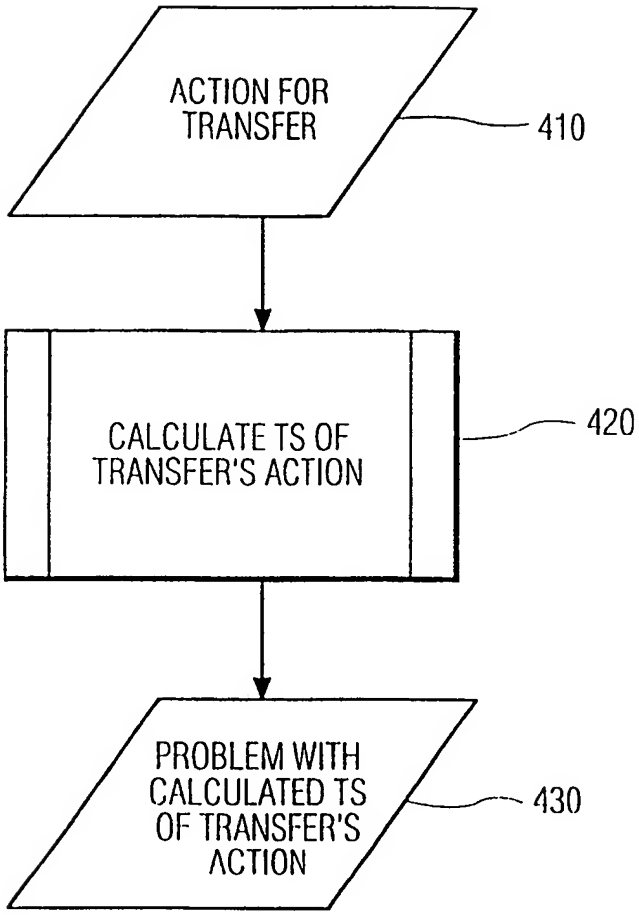

ACTION FOR TRANSFER
410
CALCULATE TS OF TRANSFER'S ACTION
420
PROBLEM WITH CALCULATED TS OF TRANSFER'S ACTION
430

FIG. 6

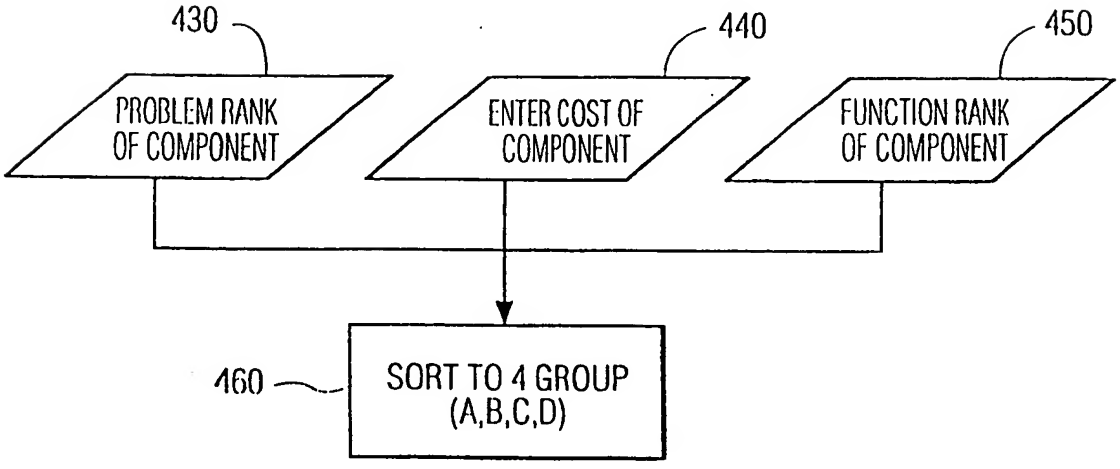

430
PROBLEM RANK OF COMPONENT
440
ENTER COST OF COMPONENT
450
FUNCTION RANK OF COMPONENT
460
SORT TO 4 GROUP (A,B,C,D)

FIG. 7

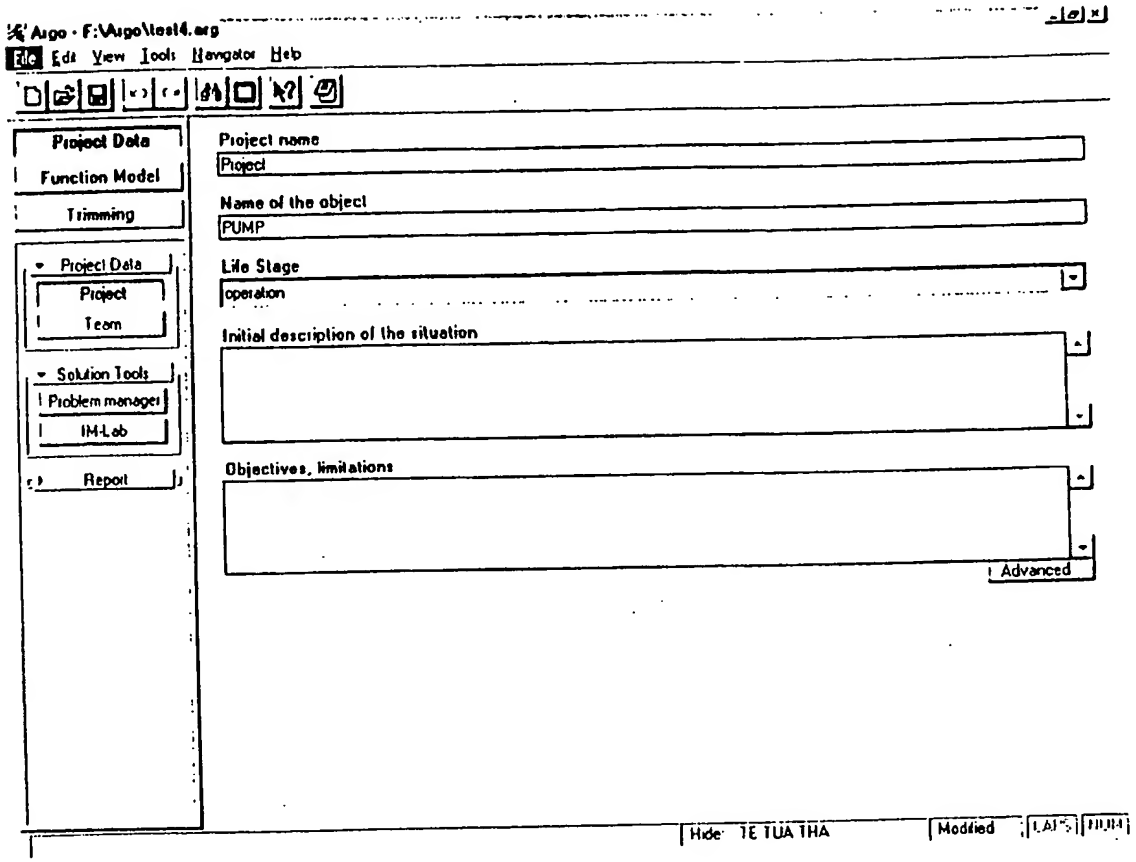

Argo - F:\Argo\test4.arg
File Edit View Tools Navigator Help
Project Data
Function Model
Trimming
Project Data
Project
Team
Solution Tools
Problem manager
IM-Lab
Report
Project name
Project
Name of the object
PUMP
Life Stage
operation
Initial description of the situation
Objectives, limitations
Advanced
Hide TE TUA THA
Modified

FIG. 8

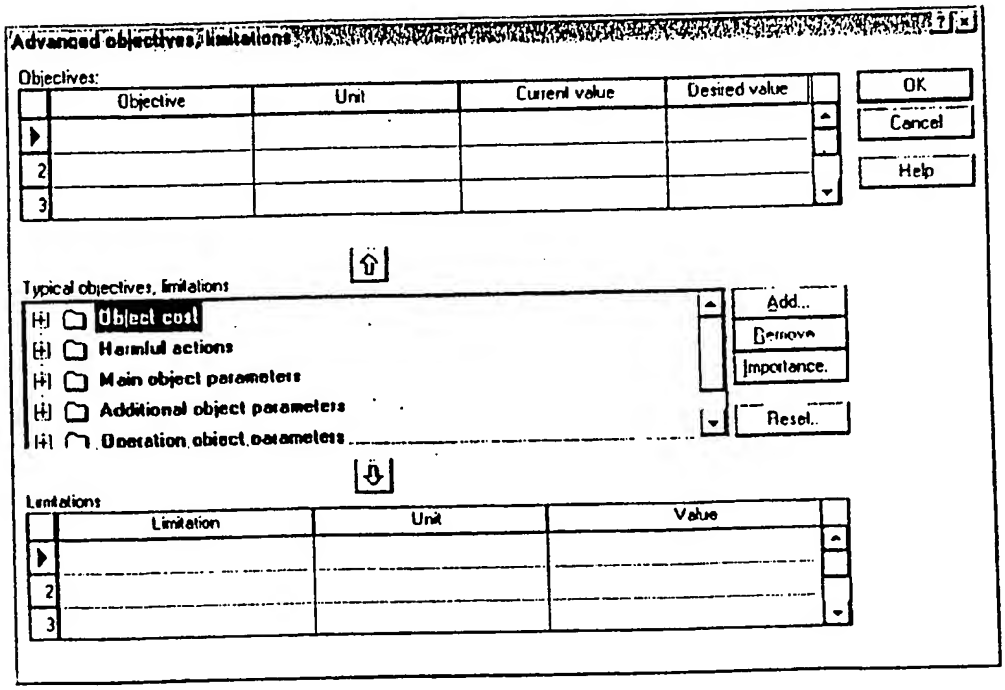

Advanced objectives, limitations
Objectives:
Objective
Unit
Current value
Desired value
OK
Cancel
Help
Typical objectives, limitations
Object cost
Harmful actions
Main object parameters
Additional object parameters
Operation object parameters
Add...
Remove
Importance...
Reset...
Limitations
Limitation
Unit
Value

FIG. 9

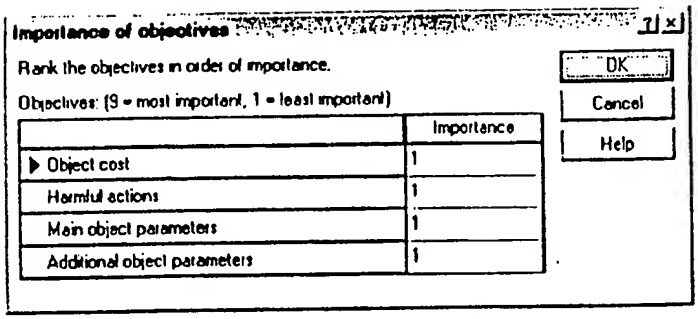

Importance of objectives
Rank the objectives in order of importance.
Objectives: (9 = most important, 1 = least important)
Importance
Object cost 1
Harmful actions 1
Main object parameters 1
Additional object parameters 1
OK
Cancel
Help

FIG. 10

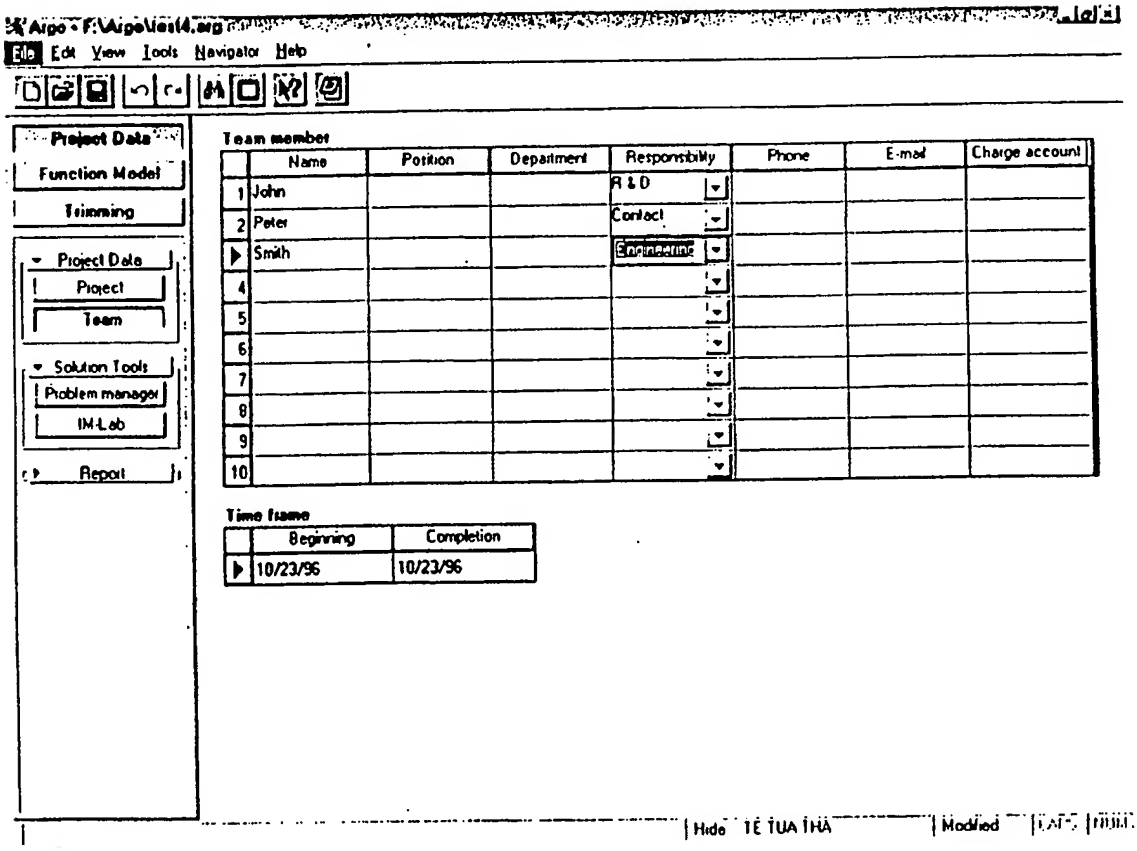

Argo - F:\Argo\test4.arg
File Edit View Tools Navigator Help
Project Data
Function Model
Trimming
Project Data
Project
Team
Solution Tools
Problem manager
IM-Lab
Report
Team member
Name Position Department Responsibility Phone E-mail Charge account
1 John R & D
2 Peter Contact
3 Smith
Time frame
Beginning Completion
10/23/96 10/23/96
Modified

FIG. 11

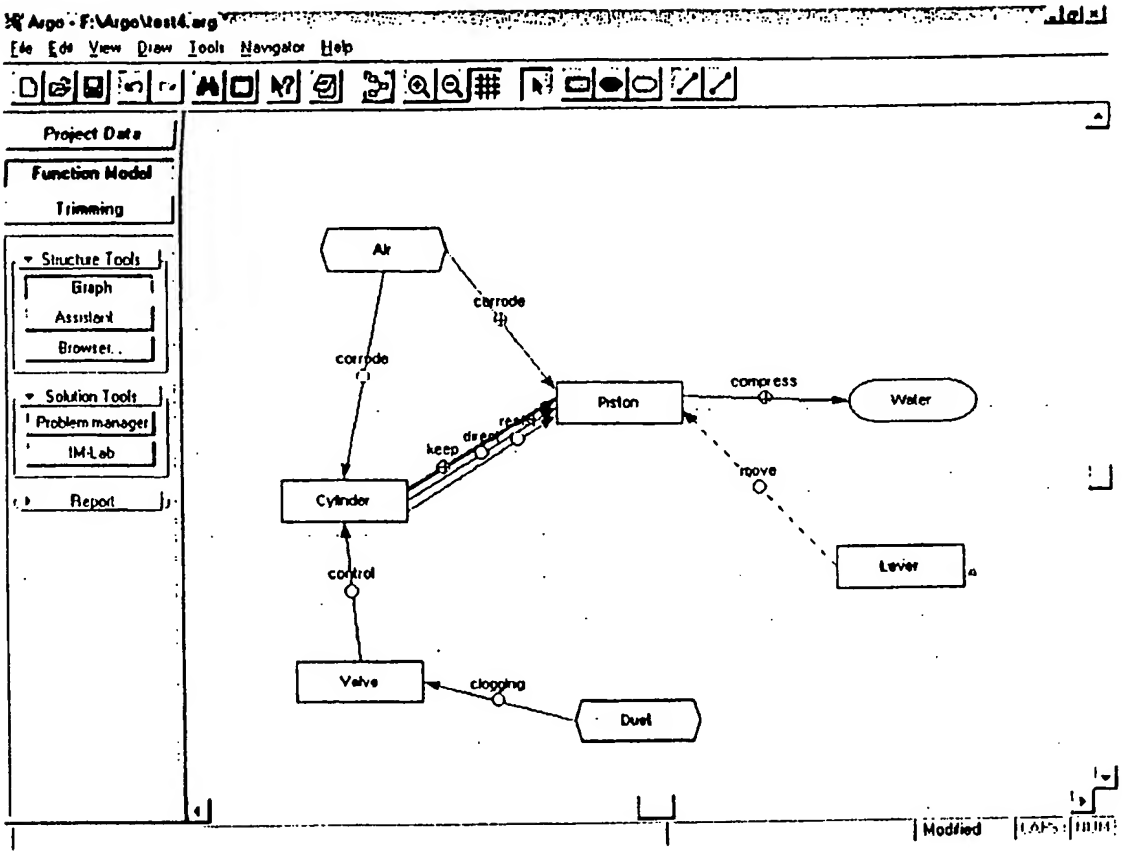

Argo - F:\Argo\test4.arg
File Edit View Draw Tools Navigator Help
Project Data
Function Model
Trimming
Structure Tools
Graph
Assistant
Browser...
Solution Tools
Problem manager
IM-Lab
Report
Air
corrode
corrode
Piston
compress
Water
keep
Cylinder
control
Valve
clogging
Duel
Lever
Modified

FIG. 12

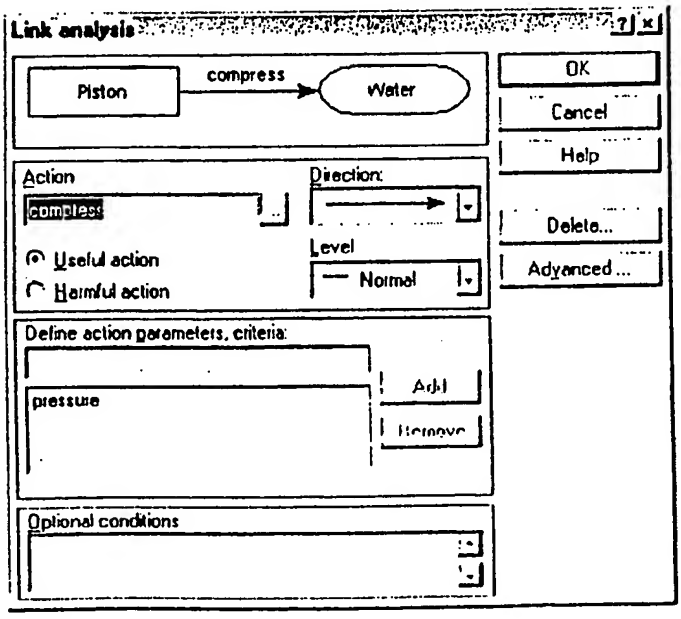

Link analysis
Piston
compress
Water
OK
Cancel
Help
Action
complies
Direction:
Useful action
Harmful action
Level
Normal
Delete...
Advanced...
Define action parameters, criteria:
pressure
Add
Remove
Optional conditions

FIG. 13

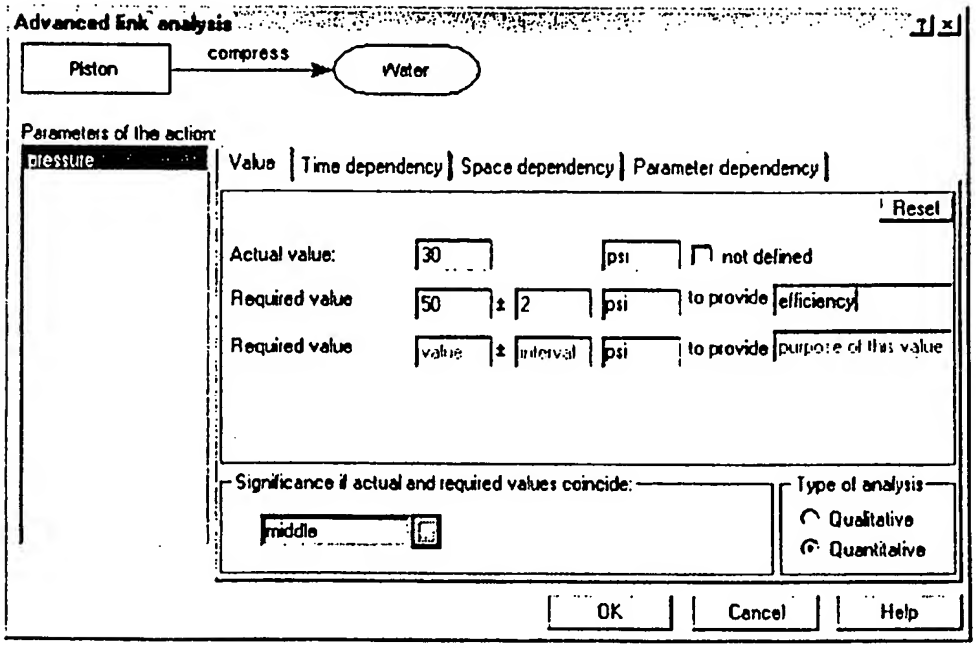

Advanced link analysis
Piston
compress
Water
Parameters of the action:
pressure
Value
Time dependency
Space dependency
Parameter dependency
Reset
Actual value:
30
psi
not defined
Required value
50
± 2
psi
to provide
efficiency
Required value
value
± interval
psi
to provide
purpose of this value
Significance if actual and required values coincide:
middle
Type of analysis
Qualitative
Quantitative
OK
Cancel
Help

FIG. 14

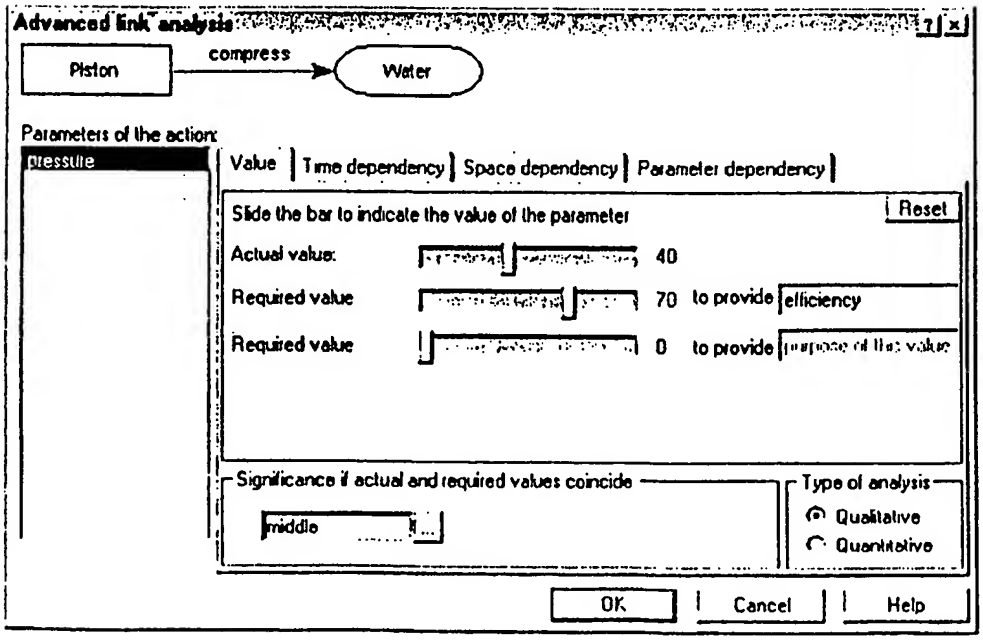

Advanced link analysis
Piston
compress
Water
Parameters of the action:
pressure
Value
Time dependency
Space dependency
Parameter dependency
Slide the bar to indicate the value of the parameter
Reset
Actual value:
40
Required value
70
to provide
efficiency
Required value
0
to provide
Significance if actual and required values coincide
middle
Type of analysis
Qualitative
Quantitative
OK
Cancel
Help

FIG. 15

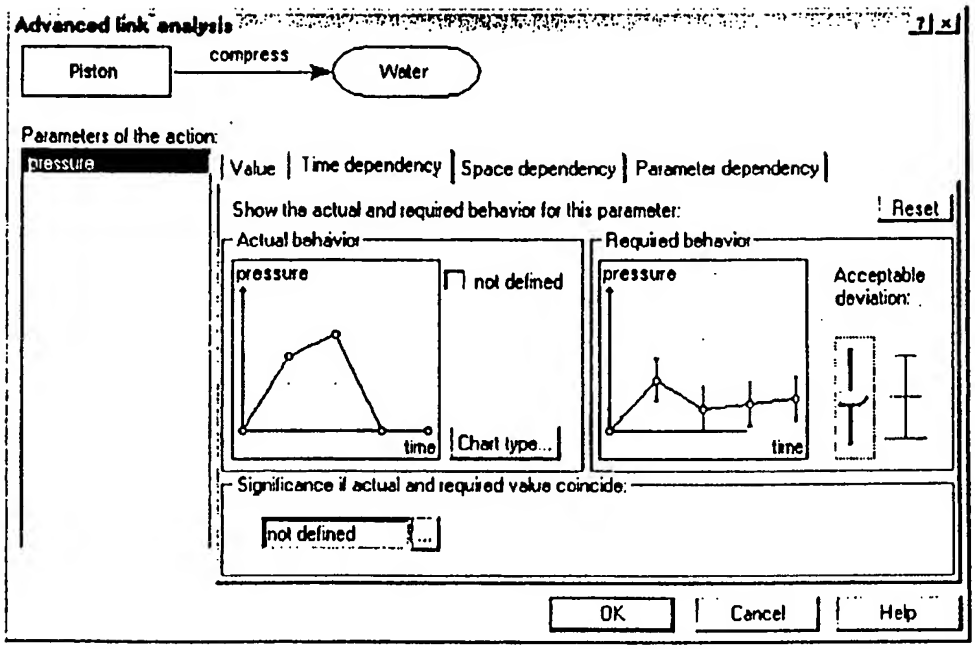
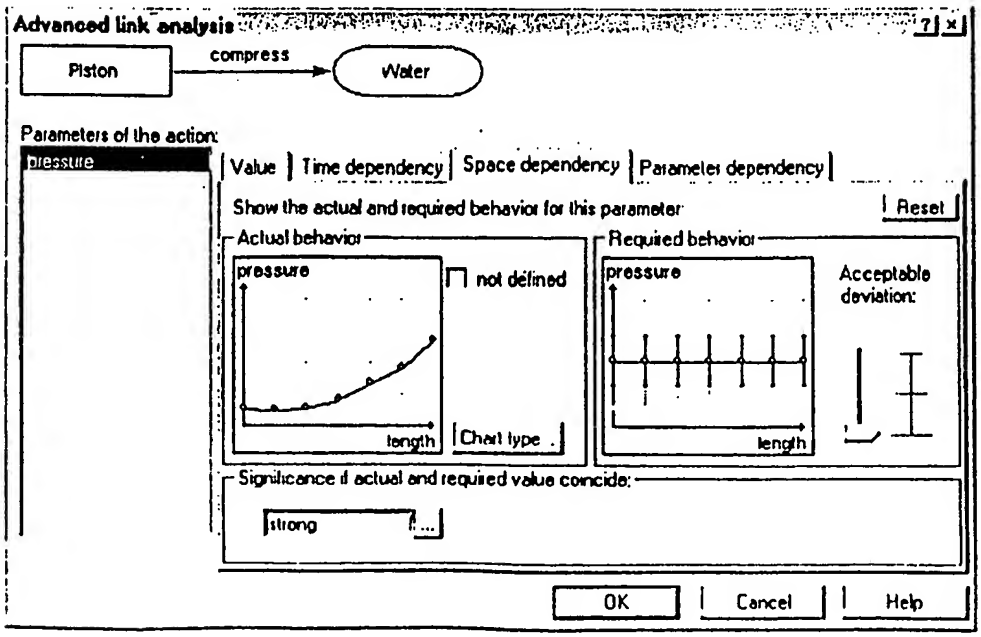

Advanced link analysis
Piston
compress
Water
Parameters of the action:
pressure
Value
Time dependency
Space dependency
Parameter dependency
Show the actual and required behavior for this parameter:
Reset
Actual behavior
pressure
not defined
time
Chart type...
Required behavior
pressure
Acceptable deviation:
time
Significance if actual and required value coincide:
not defined
OK
Cancel
Help

FIG. 16


Advanced link analysis
Piston
compress
Water
Parameters of the action:
pressure
Value
Time dependency
Space dependency
Parameter dependency
Show the actual and required behavior for this parameter:
Reset
Actual behavior
pressure
not defined
length
Chart type
Required behavior
pressure
Acceptable deviation:
length
Significance if actual and required value coincide:
strong
OK
Cancel
Help

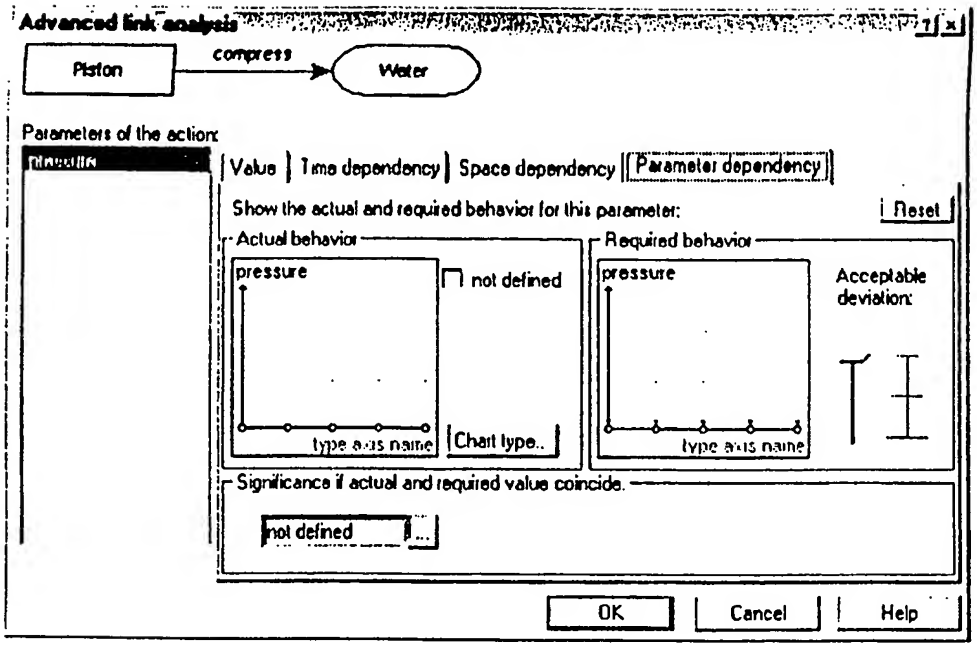
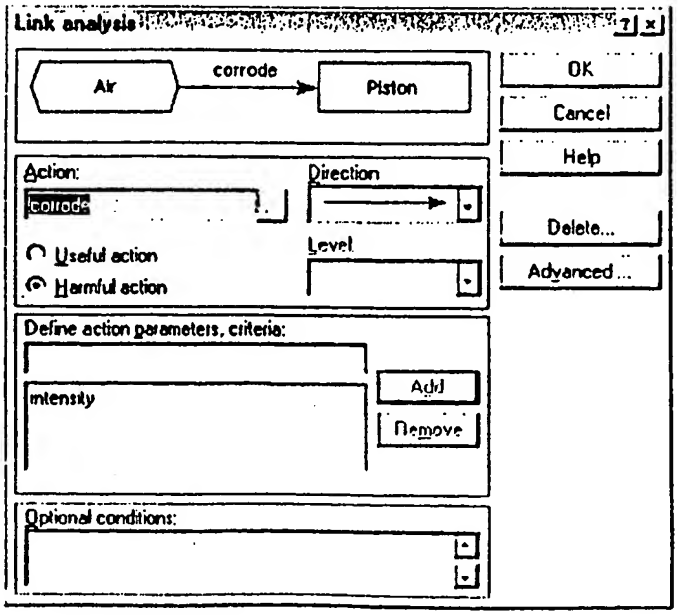

Advanced link analysis
Piston
compress
Water
Parameters of the action:
Value
Time dependency
Space dependency
Parameter dependency
Show the actual and required behavior for this parameter:
Reset
Actual behavior
pressure
not defined
type axis name
Chart type..
Required behavior
pressure
type axis name
Acceptable deviation:
Significance if actual and required value coincide:
not defined
OK
Cancel
Help

FIG. 18


Link analysis
Air
corrode
Piston
OK
Cancel
Help
Action:
corrode
Direction
Useful action
Harmful action
Level
Delete...
Advanced...
Define action parameters, criteria:
intensity
Add
Remove
Optional conditions:

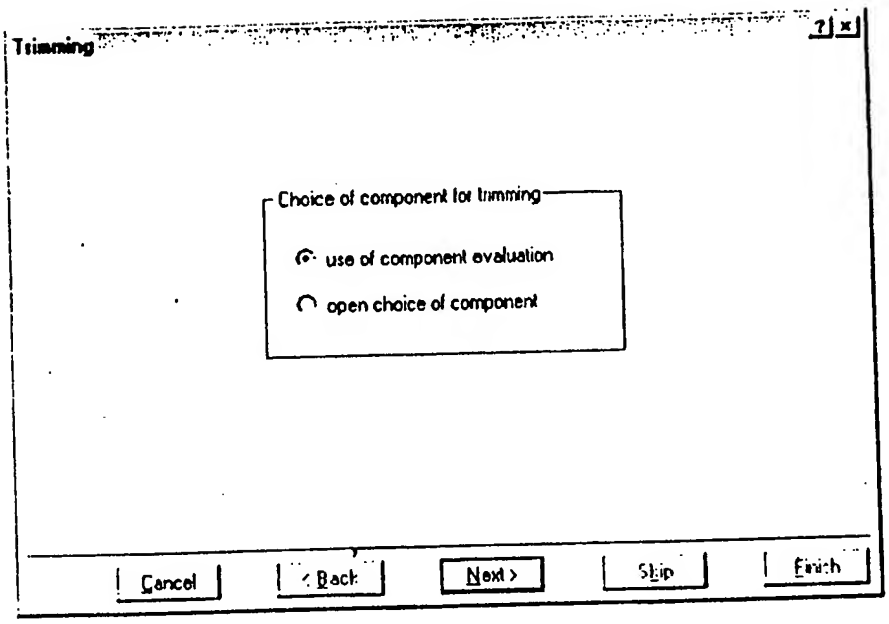

Trimming
Choice of component for trimming
use of component evaluation
open choice of component
Cancel
< Back
Next >
Skip
Finish

FIG. 20

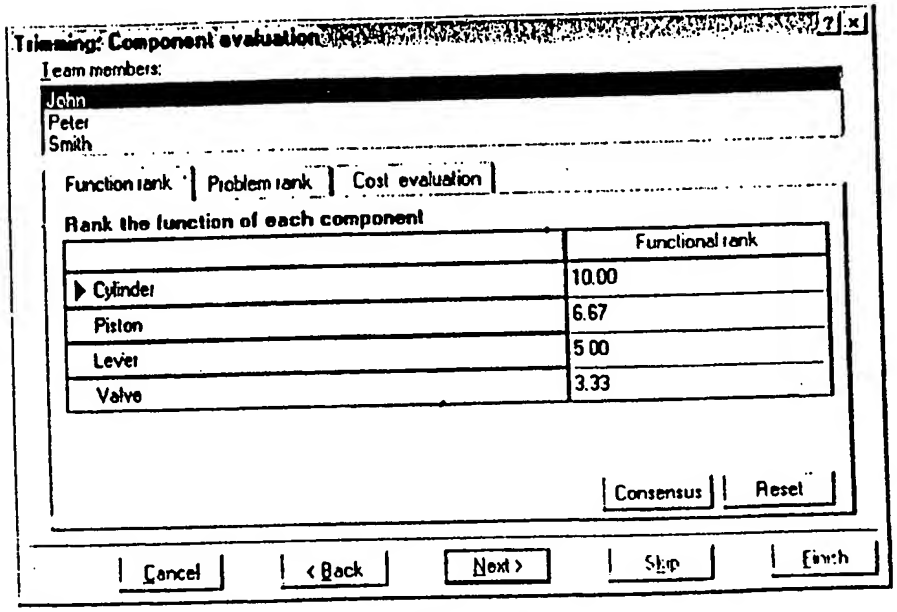

Trimming: Component evaluation
Team members:
John
Peter
Smith
Function rank
Problem rank
Cost evaluation
Rank the function of each component
Functional rank
Cylinder
10.00
Piston
6.67
Lever
5.00
Valve
3.33
Consensus
Reset
Cancel
< Back
Next >
Skip
Finish

FIG 21

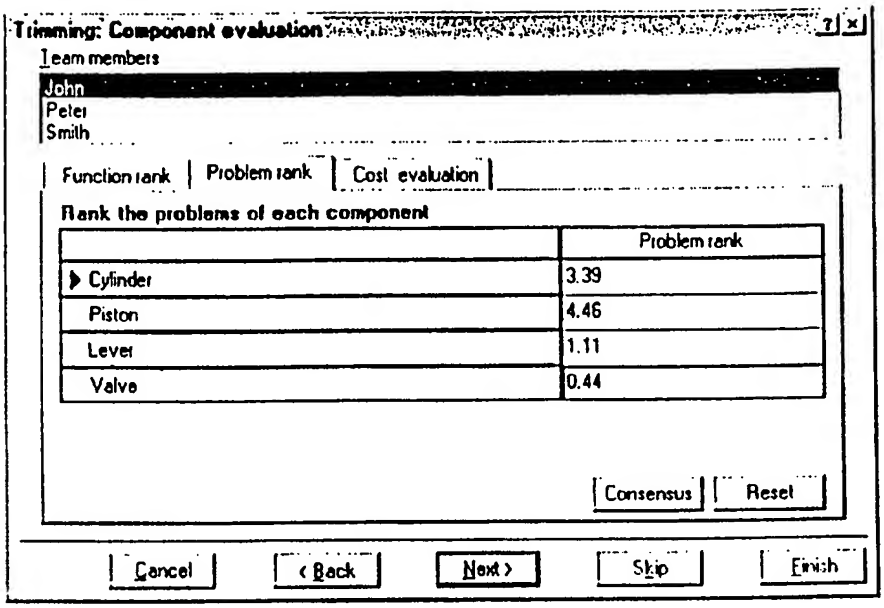

Trimming: Component evaluation
Team members
John
Peter
Smith
Function rank
Problem rank
Cost evaluation
Rank the problems of each component
Problem rank
Cylinder
3.39
Piston
4.46
Lever
1.11
Valve
0.44
Consensus
Reset
Cancel
< Back
Next >
Skip
Finish

FIG. 22

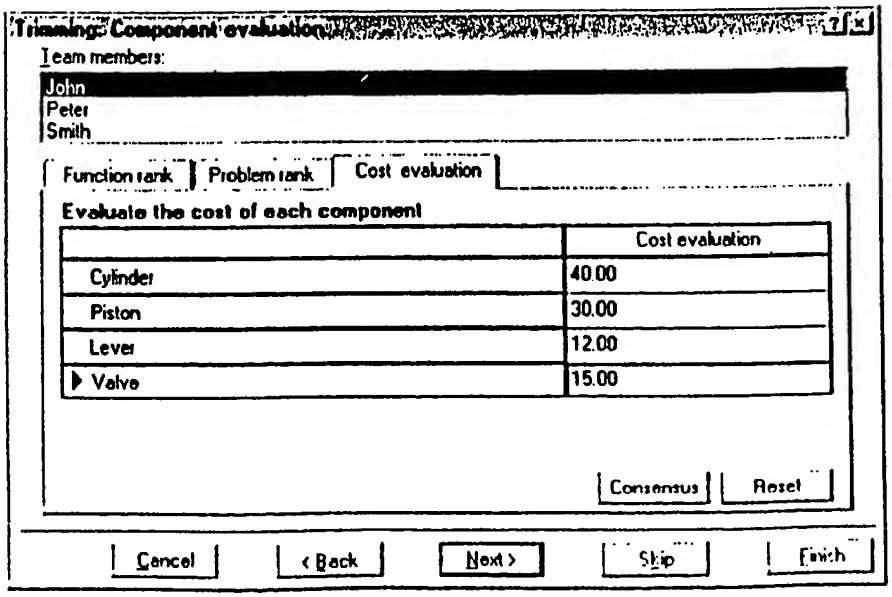

Trimming: Component evaluation
Team members:
John
Peter
Smith
Function rank
Problem rank
Cost evaluation
Evaluate the cost of each component
Cost evaluation
Cylinder
40.00
Piston
30.00
Lever
12.00
Valve
15.00
Consensus
Reset
Cancel
< Back
Next >
Skip
Finish

FIG. 23

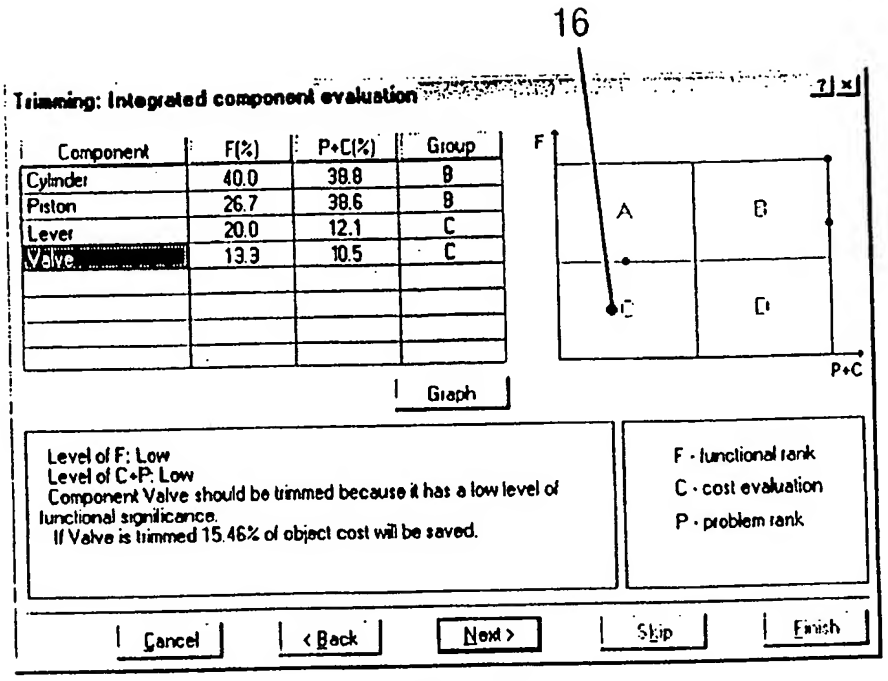

16
Trimming: Integrated component evaluation
Component
F(%)
P+C(%)
Group
Cylinder
40.0
38.8
B
Piston
26.7
38.6
B
Lever
20.0
12.1
C
Valve
13.3
10.5
C
Graph
F
A
B
C
D
P+C
Level of F: Low
Level of C+P: Low
Component Valve should be trimmed because it has a low level of functional significance.
If Valve is trimmed 15.46% of object cost will be saved.
F - functional rank
C - cost evaluation
P - problem rank
Cancel
< Back
Next >
Skip
Finish

FIG. 24

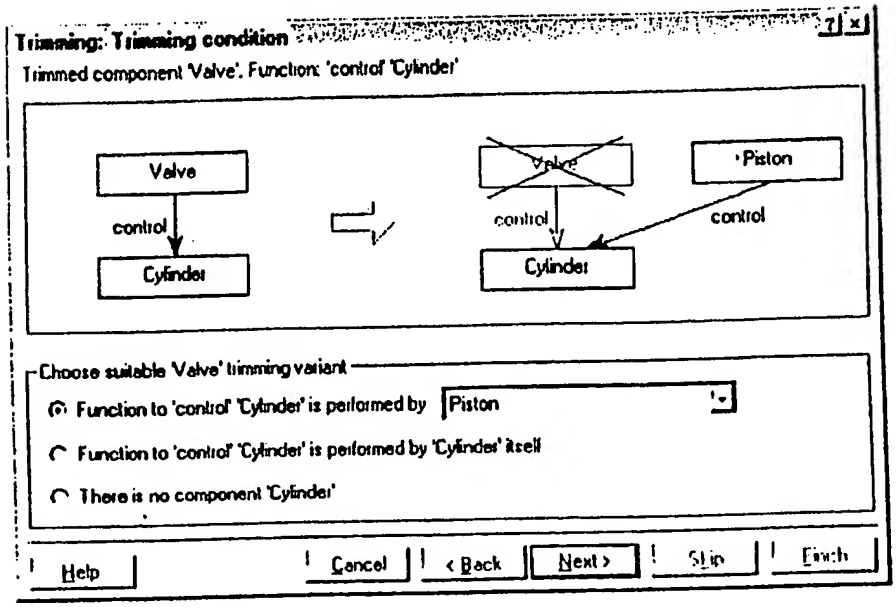

Trimming: Trimming condition
Trimmed component 'Valve'. Function: 'control' 'Cylinder'
Valve
control
Cylinder
Valve
Piston
control
control
Cylinder
Choose suitable 'Valve' trimming variant
Function to 'control' 'Cylinder' is performed by
Piston
Function to 'control' 'Cylinder' is performed by 'Cylinder' itself
There is no component 'Cylinder'
Help
Cancel
< Back
Next >
Skip
Finish

FIG. 25

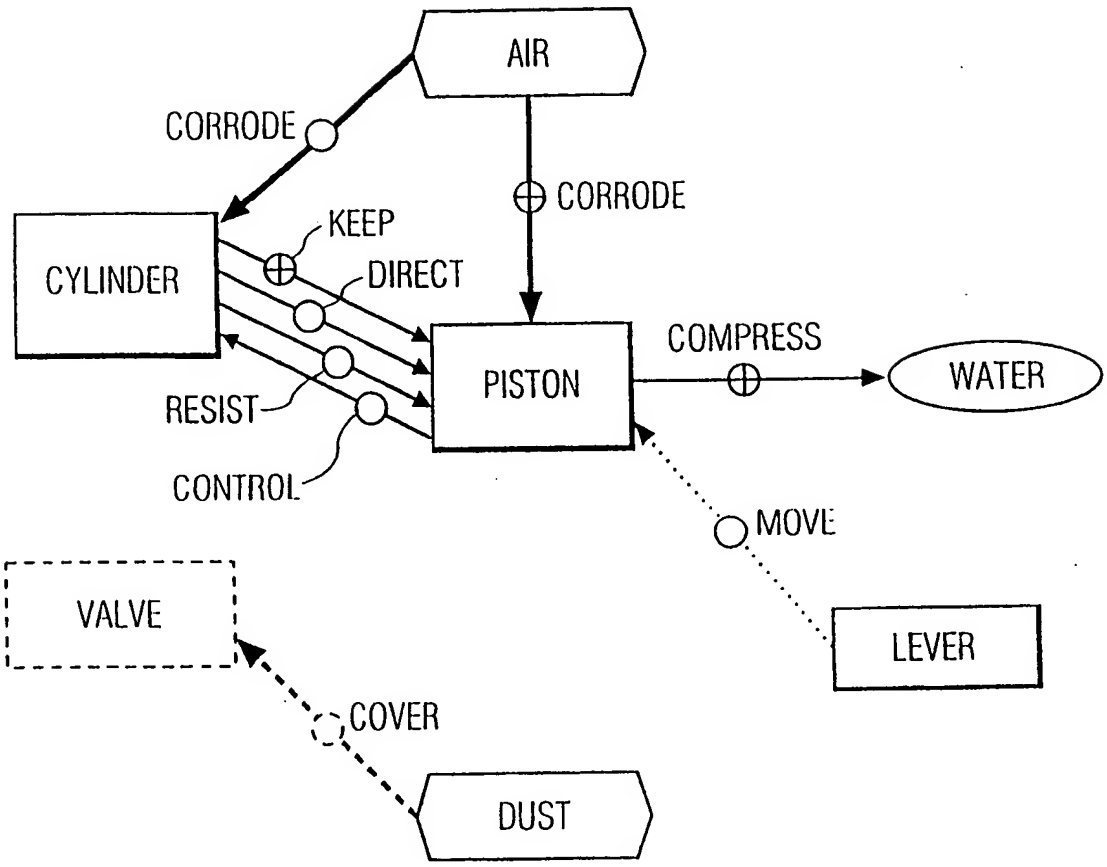

AIR
CORRODE
CORRODE
KEEP
CYLINDER
DIRECT
PISTON
COMPRESS
WATER
RESIST
CONTROL
MOVE
VALVE
LEVER
COVER
DUST

FIG. 26

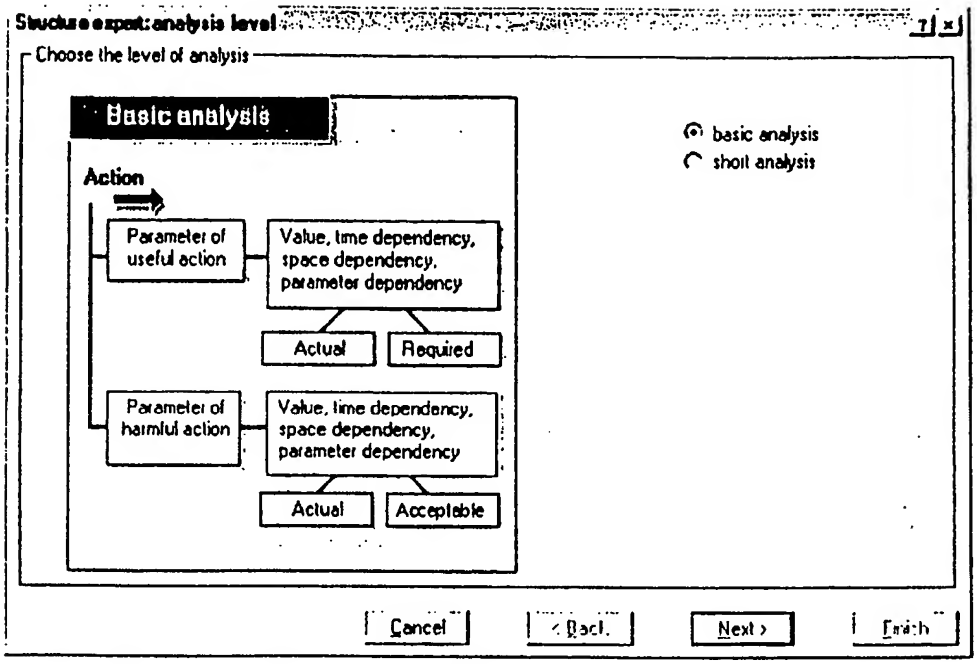

Structure expert: analysis level
Choose the level of analysis
Basic analysis
Action
Parameter of useful action
Value, time dependency, space dependency, parameter dependency
Actual
Required
Parameter of harmful action
Value, time dependency, space dependency, parameter dependency
Actual
Acceptable
basic analysis
short analysis
Cancel
< Back
Next >
Finish

FIG. 27

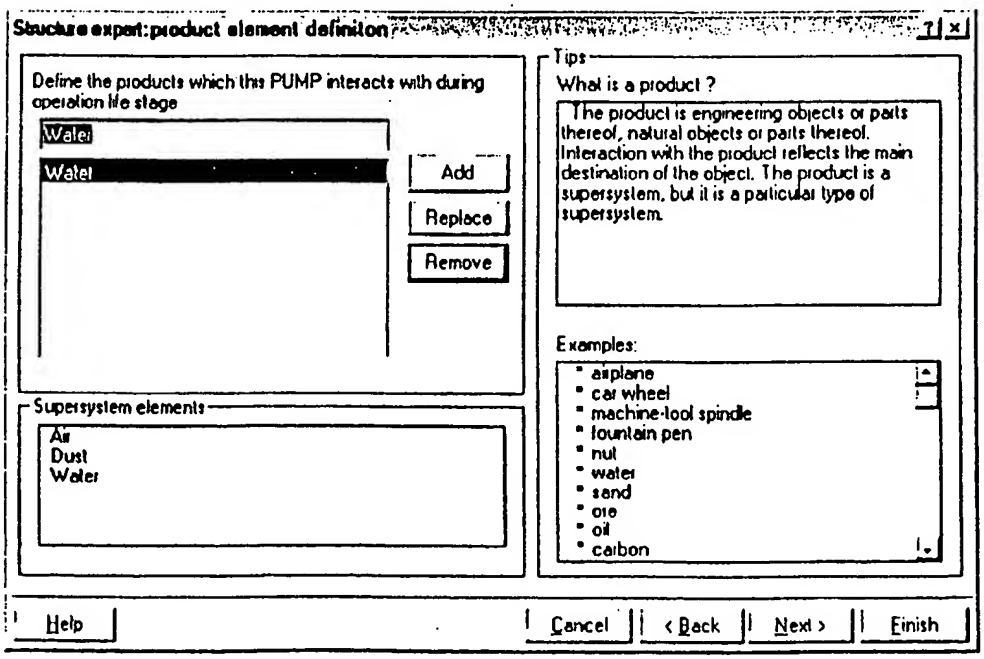

Structure expert: product element definition
Define the products which this PUMP interacts with during operation life stage
Water
Water
Add
Replace
Remove
Supersystem elements
Air
Dust
Water
Tips
What is a product ?
The product is engineering objects or parts thereof, natural objects or parts thereof. Interaction with the product reflects the main destination of the object. The product is a supersystem, but it is a particular type of supersystem.
Examples:
airplane
car wheel
machine-tool spindle
fountain pen
nut
water
sand
ore
oil
carbon
Help
Cancel
< Back
Next >
Finish

FIG. 28

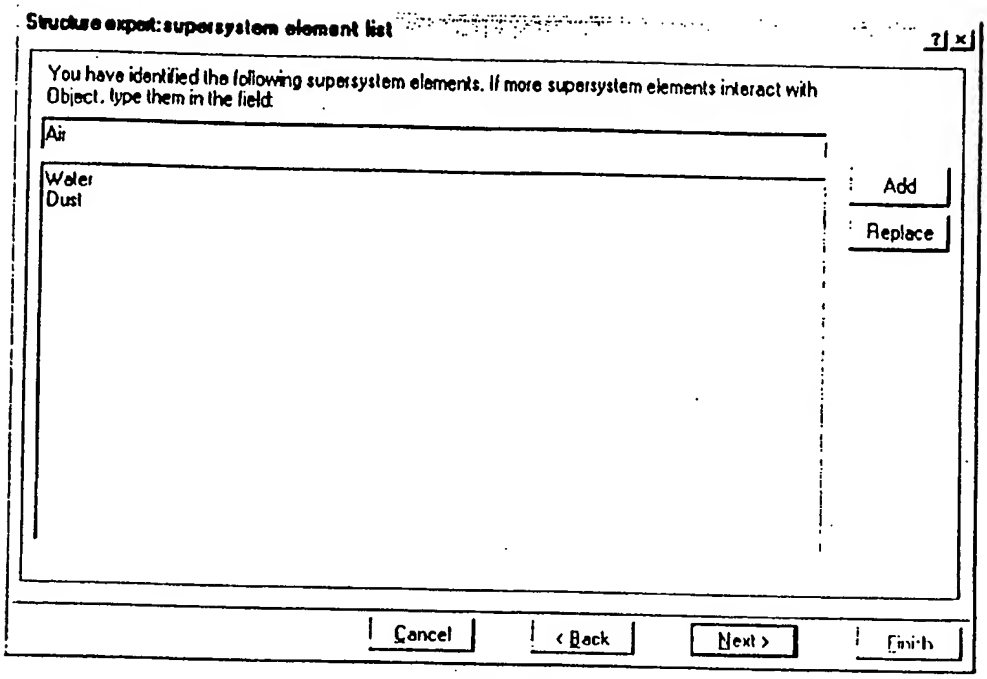

Structure expert: supersystem element list
You have identified the following supersystem elements. If more supersystem elements interact with Object, type them in the field
Air
Water
Dust
Add
Replace
Cancel
< Back
Next >
Finish

FIG. 29

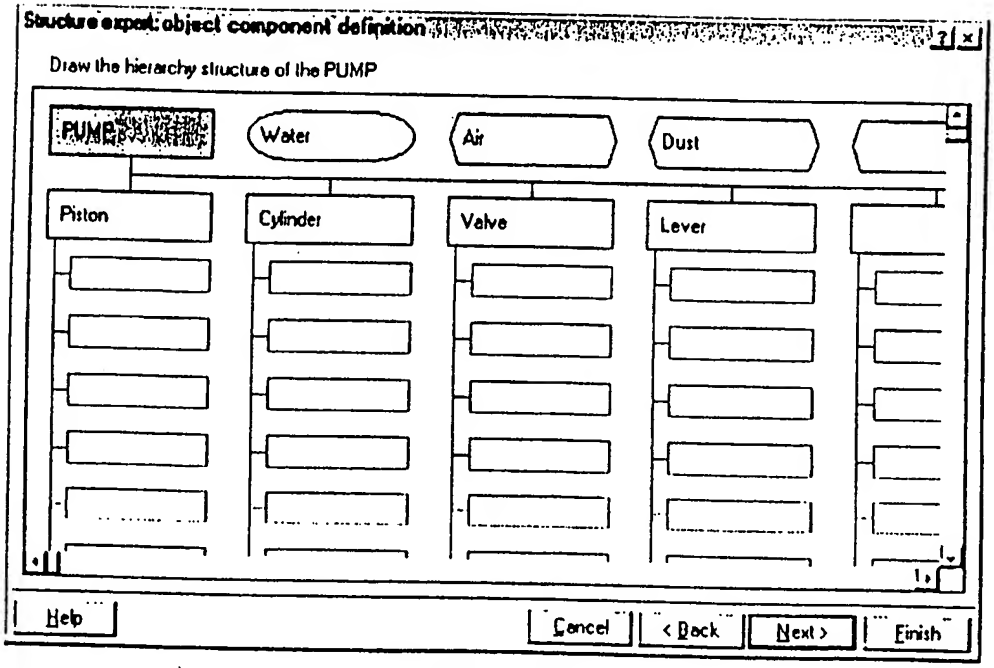

Structure expert: object component definition
Draw the hierarchy structure of the PUMP
PUMP
Water
Air
Dust
Piston
Cylinder
Valve
Lever
Help
Cancel
< Back
Next >
Finish

FIG. 30

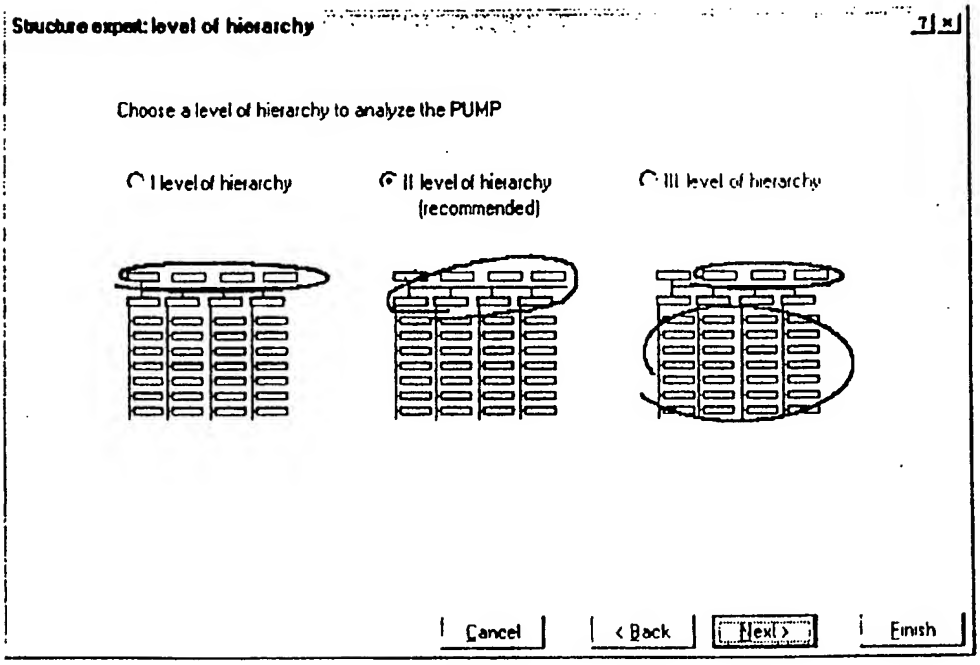
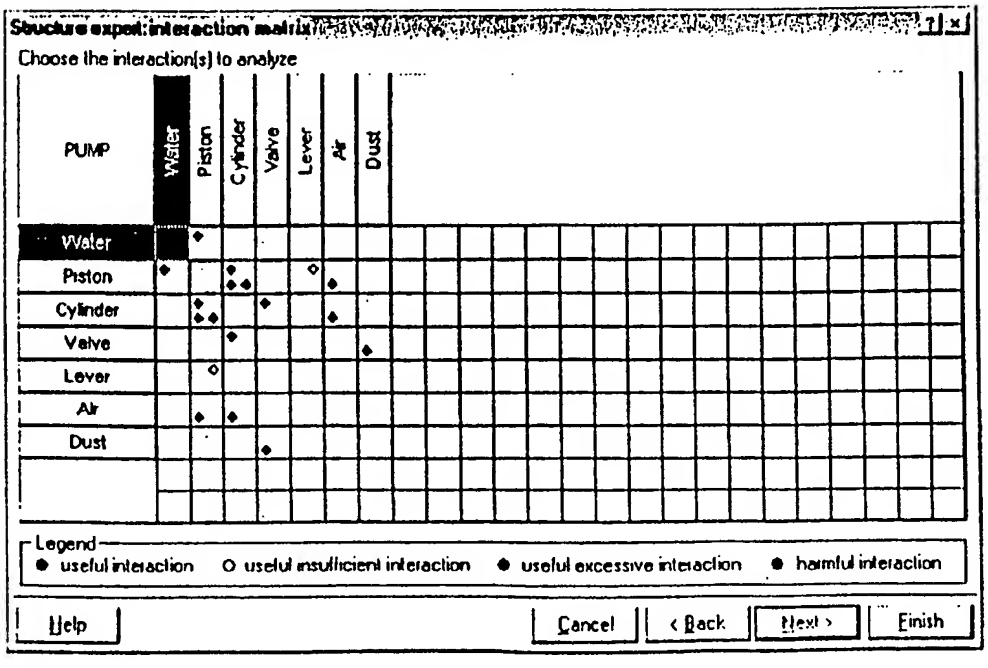

Stucture expat: level of hierarchy
Choose a level of hierarchy to analyze the PUMP
I level of hierarchy
II level of hierarchy (recommended)
III level of hierarchy
Cancel
< Back
Next >
Finish

FIG. 31


Stucture expat: interaction matrix
Choose the interaction(s) to analyze
PUMP
Water
Piston
Cylinder
Valve
Lever
Air
Dust
Legend
useful interaction
useful insufficient interaction
useful excessive interaction
harmful interaction
Help
Cancel
< Back
Next >
Finish

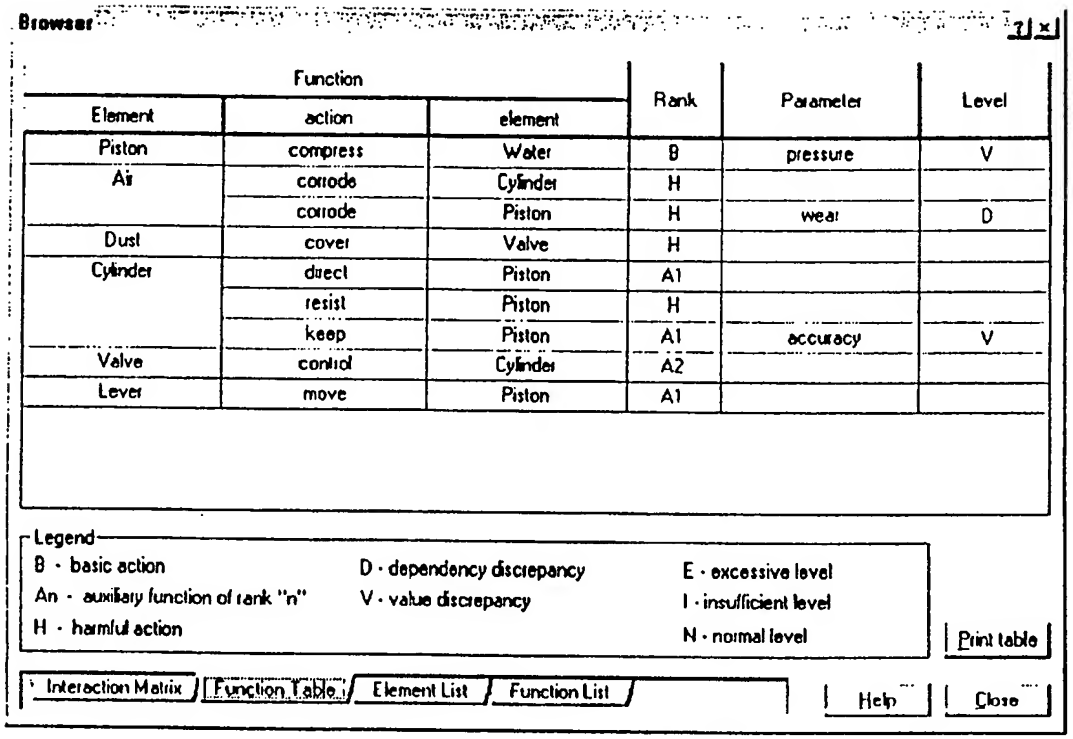

Browser
Function
Element
action
element
Rank
Parameter
Level
Piston
compress
Water
B
pressure
V
Air
corrode
Cylinder
H
corrode
Piston
H
wear
D
Dust
cover
Valve
H
Cylinder
direct
Piston
A1
resist
Piston
H
keep
Piston
A1
accuracy
V
Valve
control
Cylinder
A2
Lever
move
Piston
A1
Legend
B - basic action
An - auxiliary function of rank "n"
H - harmful action
D - dependency discrepancy
V - value discrepancy
E - excessive level
I - insufficient level
N - normal level
Print table
Interaction Matrix
Function Table
Element List
Function List
Help
Close

FIG. 33

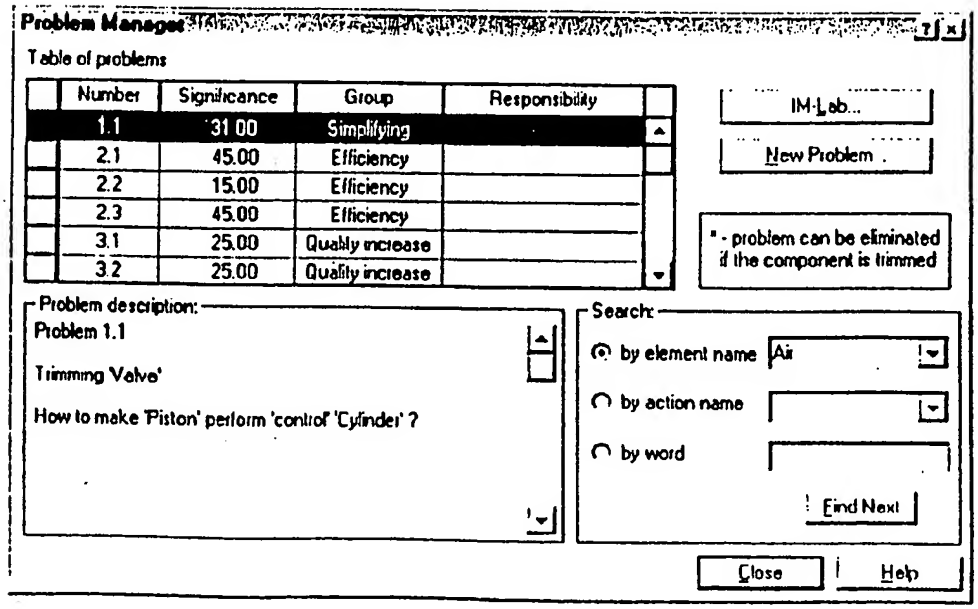

Problem Manager
Table of problems
Number
Significance
Group
Responsibility
1.1
31.00
Simplifying
2.1
45.00
Efficiency
2.2
15.00
Efficiency
2.3
45.00
Efficiency
3.1
25.00
Quality increase
3.2
25.00
Quality increase
IM-Lab...
New Problem...
* - problem can be eliminated if the component is trimmed
Problem description:
Problem 1.1
Trimmng Valve'
How to make 'Piston' perform 'control' 'Cylinder' ?
Search:
by element name
Air
by action name
by word
Find Next
Close
Help

FIG. 34

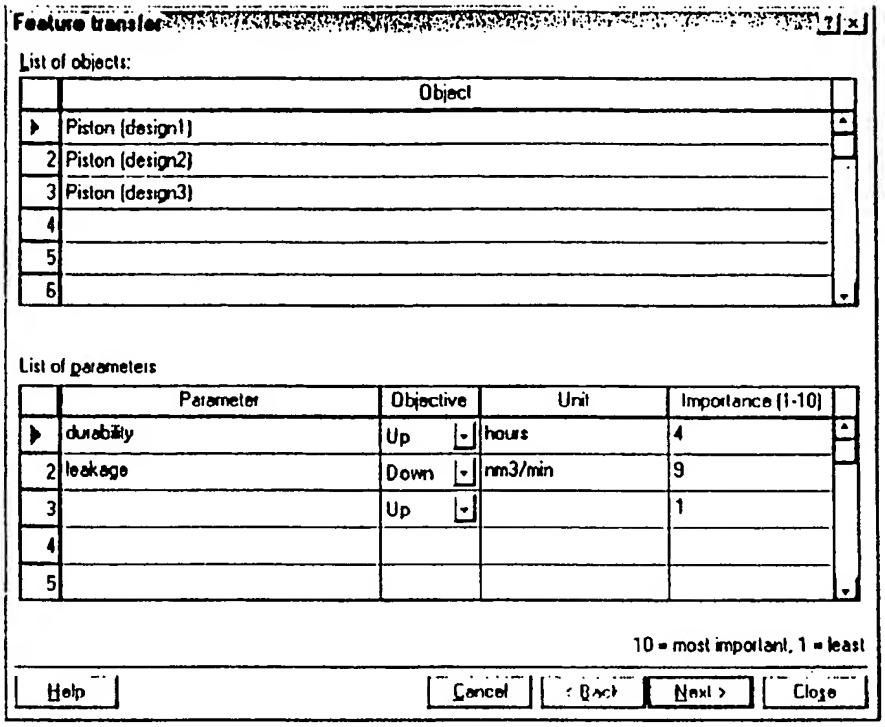

Feature transfer
List of objects:
Object
1 Piston (design1)
2 Piston (design2)
3 Piston (design3)
4
5
6
List of parameters
Parameter
Objective
Unit
Importance (1-10)
1 durability Up hours 4
2 leakage Down nm3/min 9
3 Up 1
4
5
10 = most important, 1 = least
Help
Cancel
< Back
Next >
Close

FIG. 35

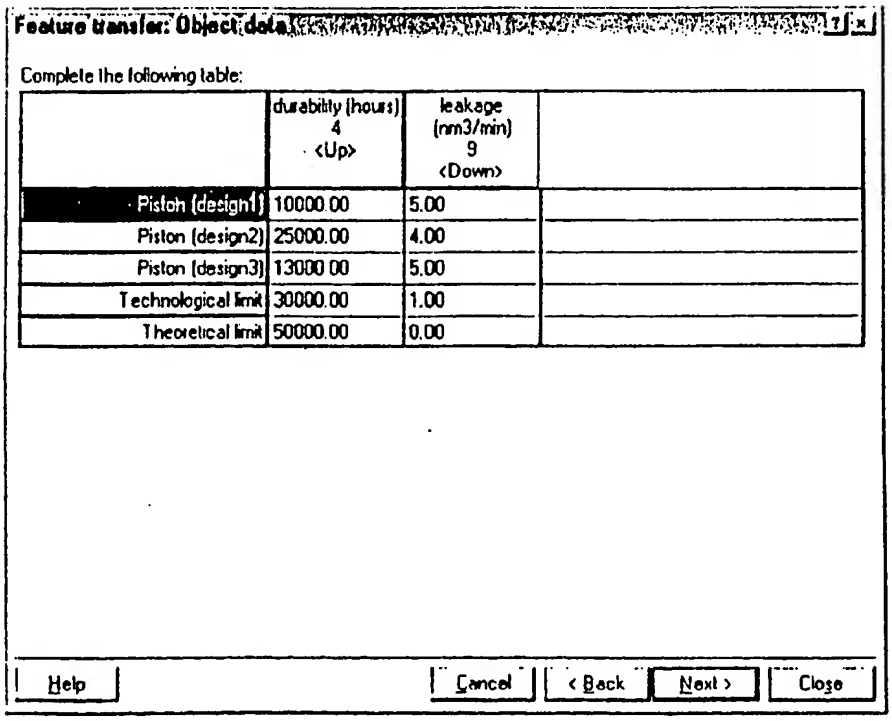

Feature transfer: Object data
Complete the following table:
durability (hours) 4 <Up>
leakage (nm3/min) 9 <Down>
Piston (design1) 10000.00 5.00
Piston (design2) 25000.00 4.00
Piston (design3) 13000.00 5.00
Technological limit 30000.00 1.00
Theoretical limit 50000.00 0.00
Help
Cancel
< Back
Next >
Close

FIG. 36

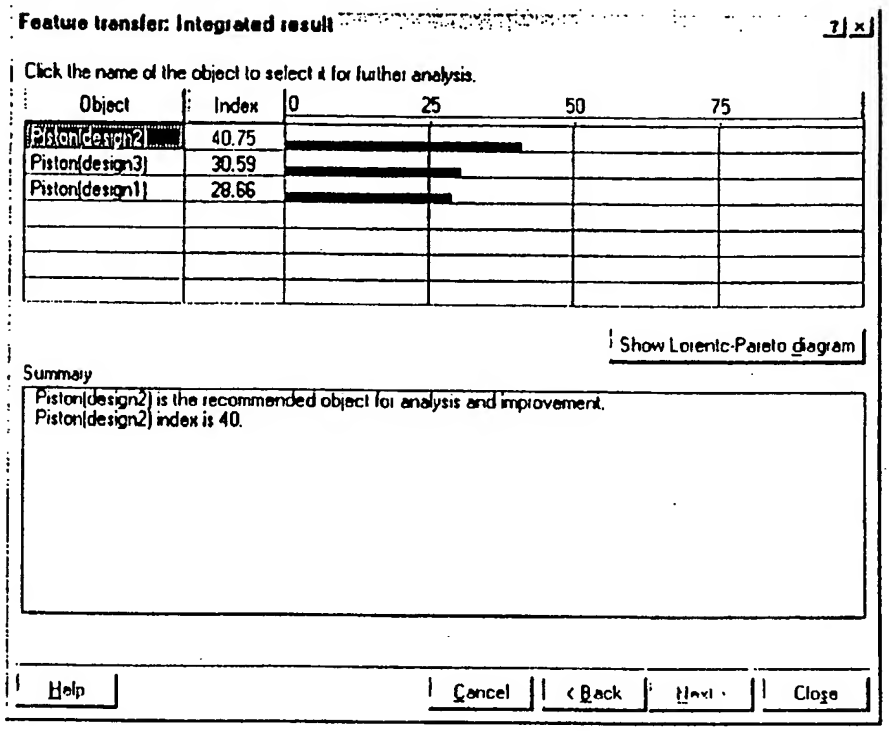

Feature transfer: Integrated result
Click the name of the object to select it for further analysis.
Object
Index
0
25
50
75
Piston(design2)
40.75
Piston(design3)
30.59
Piston(design1)
28.66
Show Lorentz-Pareto diagram
Summary
Piston(design2) is the recommended object for analysis and improvement.
Piston(design2) index is 40.
Help
Cancel
< Back
Next >
Close

FIG. 37

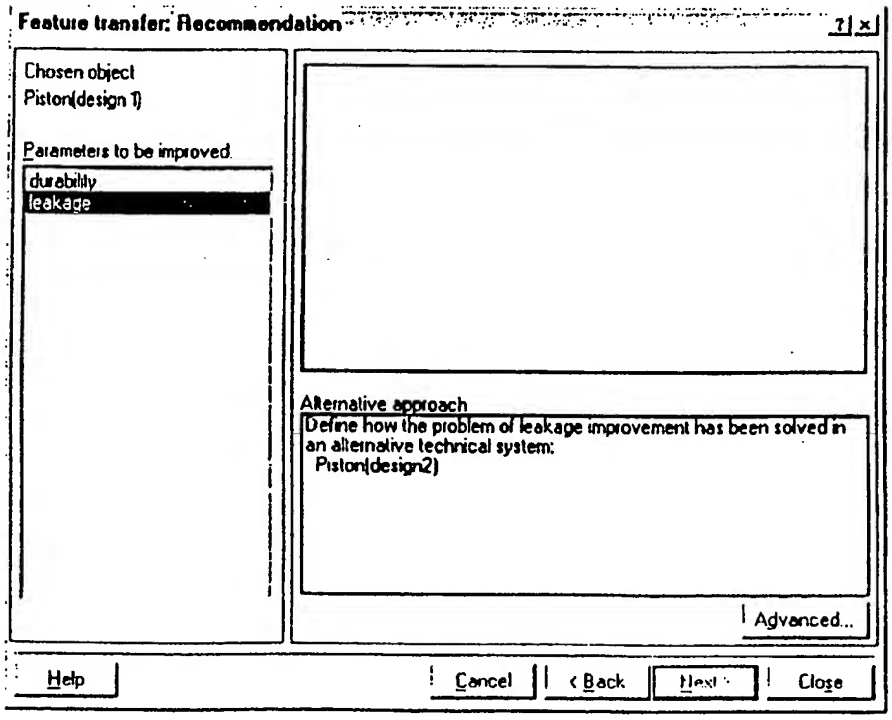

Feature transfer: Recommendation
Chosen object
Piston(design 1)
Parameters to be improved
durability
leakage
Alternative approach
Define how the problem of leakage improvement has been solved in an alternative technical system:
Piston(design2)
Advanced...
Help
Cancel
< Back
Next >
Close

FIG. 38

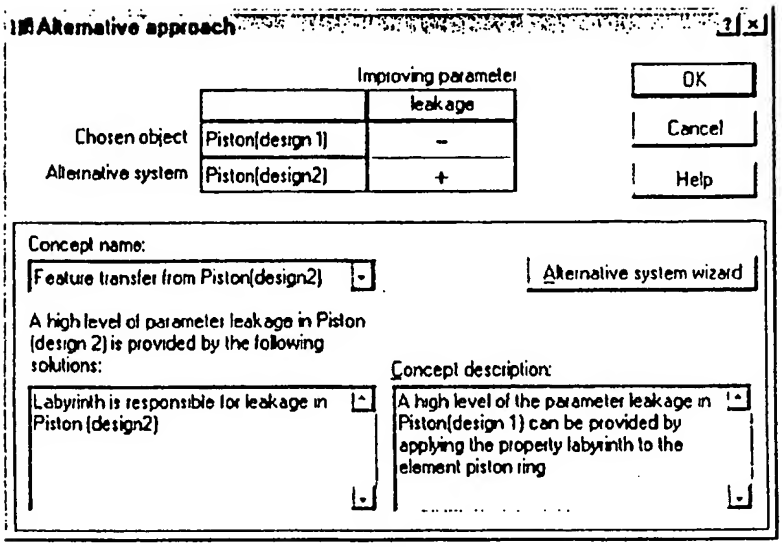

Alternative approach
Improving parameter
leakage
Chosen object
Piston(design 1)
-
Alternative system
Piston(design2)
+
OK
Cancel
Help
Concept name:
Feature transfer from Piston(design2)
Alternative system wizard
A high level of parameter leakage in Piston (design 2) is provided by the following solutions:
Concept description:
Labyrinth is responsible for leakage in Piston (design2)
A high level of the parameter leakage in Piston(design 1) can be provided by applying the property labyrinth to the element piston ring

FIG. 39

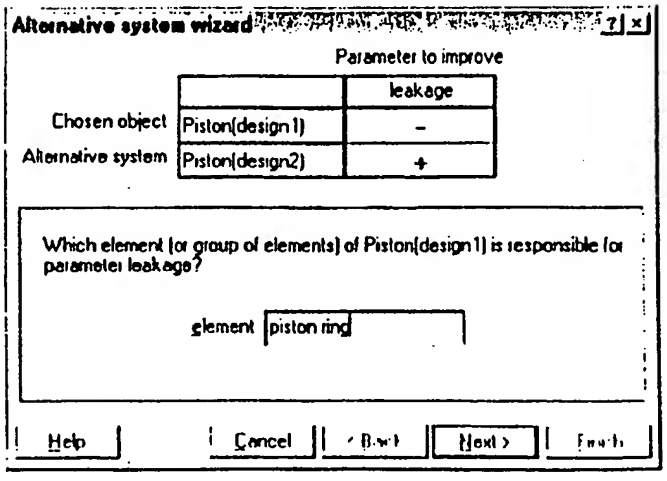

Alternative system wizard
Parameter to improve
leakage
Chosen object
Piston(design 1)
-
Alternative system
Piston(design2)
+
Which element (or group of elements) of Piston(design1) is responsible for parameter leakage?
element
piston ring
Help
Cancel
Next >

FIG. 40

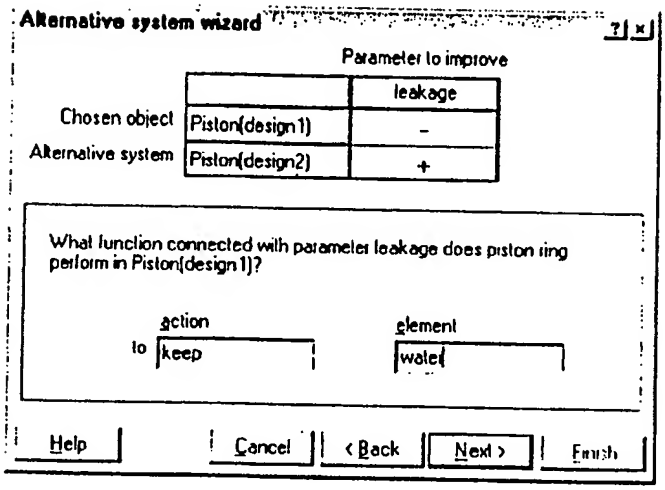

Alternative system wizard
Parameter to improve
leakage
Chosen object
Piston(design1)
-
Alternative system
Piston(design2)
+
What function connected with parameter leakage does piston ring perform in Piston(design1)?
action
to
keep
element
water
Help
Cancel
< Back
Next >
Finish

FIG. 41

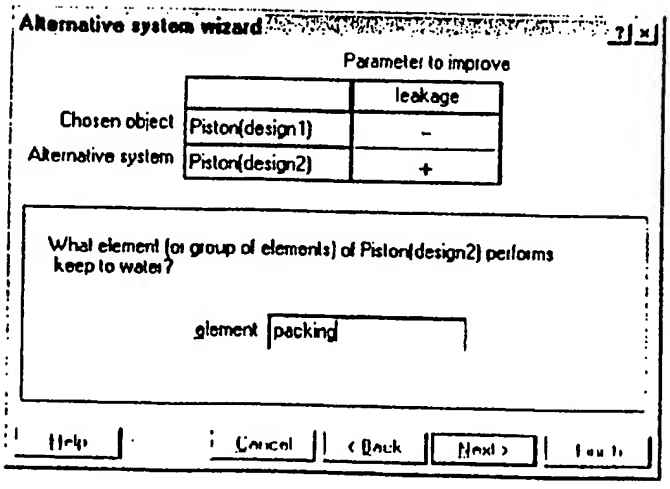

Alternative system wizard
Parameter to improve
leakage
Chosen object
Piston(design1)
-
Alternative system
Piston(design2)
+
What element (or group of elements) of Piston(design2) performs keep to water?
element
packing
Help
Cancel
< Back
Next >

FIG. 42

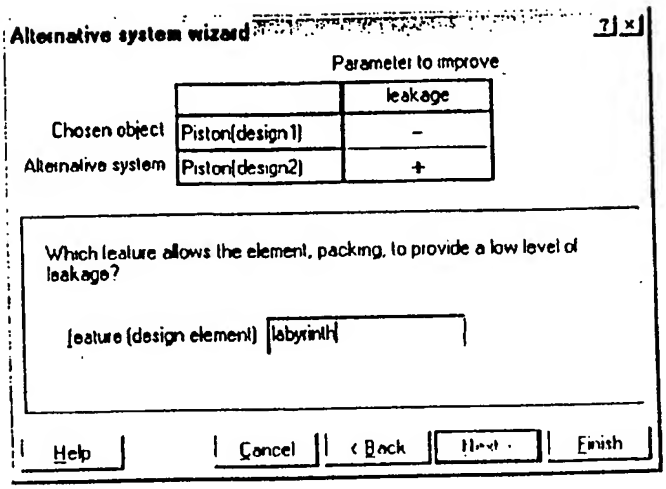

Alternative system wizard
Parameter to improve
leakage
Chosen object
Piston(design1)
-
Alternative system
Piston(design2)
+
Which feature allows the element, packing, to provide a low level of leakage?
feature (design element)
labyrinth
Help
Cancel
< Back
Next >
Finish

FIG. 43

COMPONENT CAN BE ELIMINATED IF:

1) ITS ACTION IS PERFORMED BY ANOTHER COMPONENT OR SUPERSYSTEM ELEMENT:

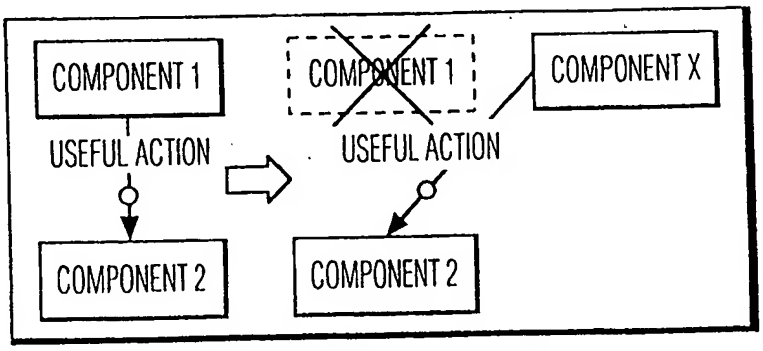


FIG. 44A

2) ITS ACTION IS PERFORMED BY THE COMPONENT WHICH RECEIVES THE ACTION:

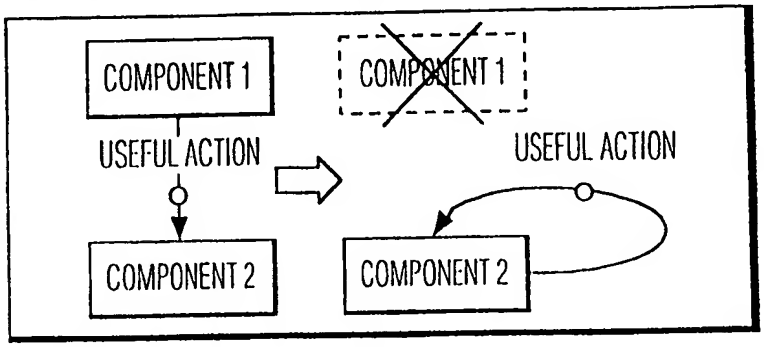


FIG. 44B

3) ITS COMPONENT WHICH RECEIVES THE ACTION IS ALSO ELIMINATED:

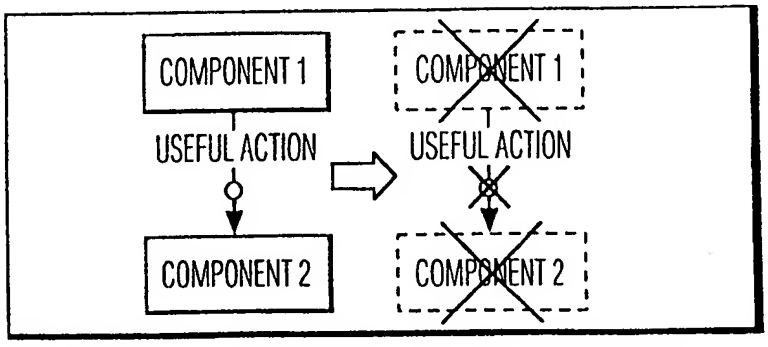


FIG. 44C

THERE ARE TWO WAYS TO TRANSFORM AN ACTION APPLIED TO A TRIMMED ELEMENT:

1) ACTION CAN BE APPLIED TO ANOTHER ELEMENT:

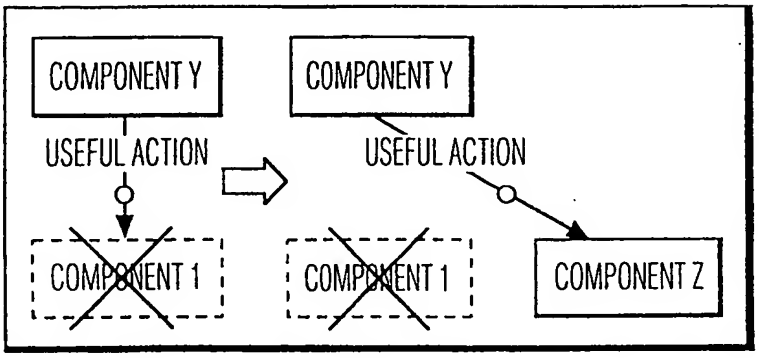


FIG. 44D

2) ACTION CAN BE DELETED:

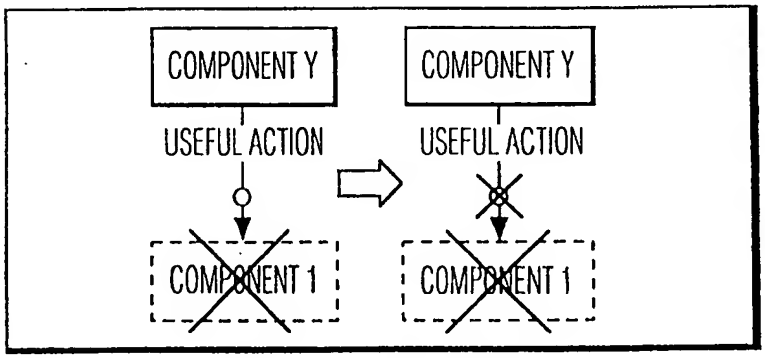
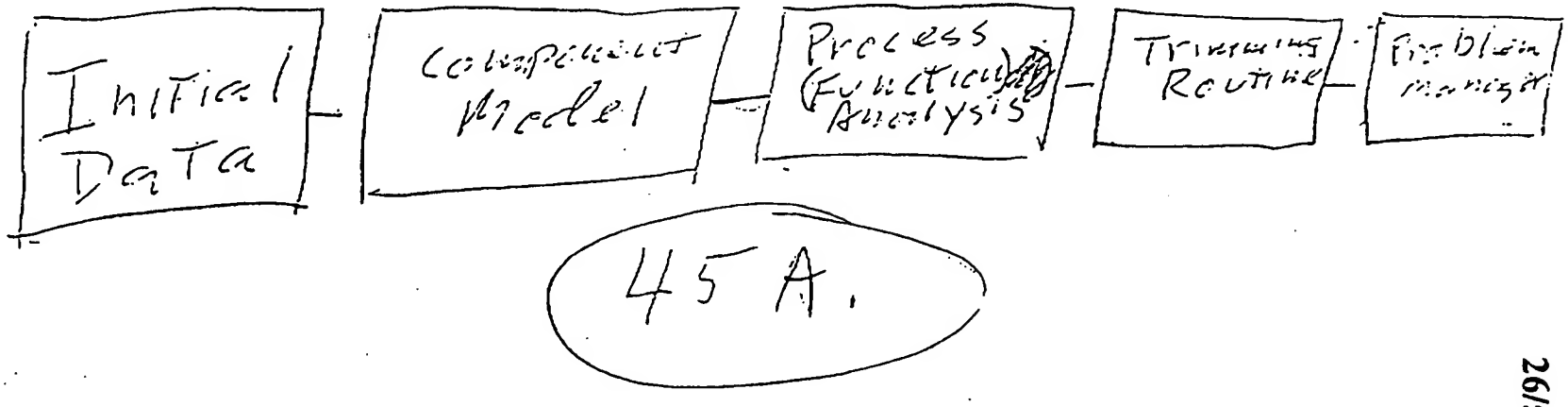
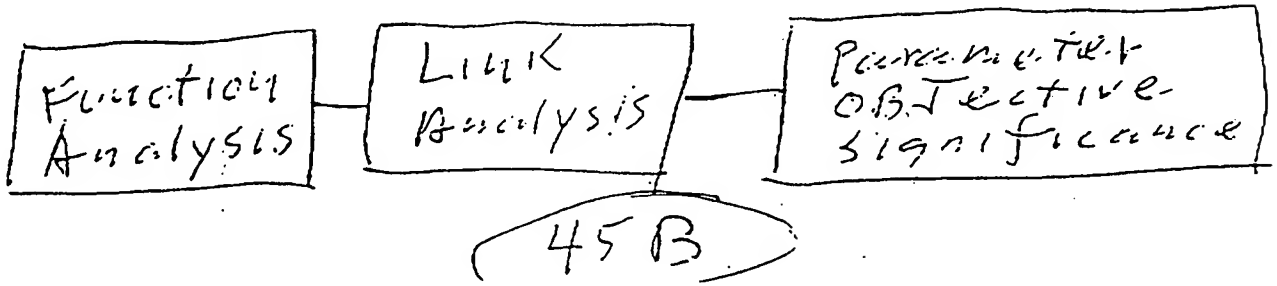


FIG. 44E

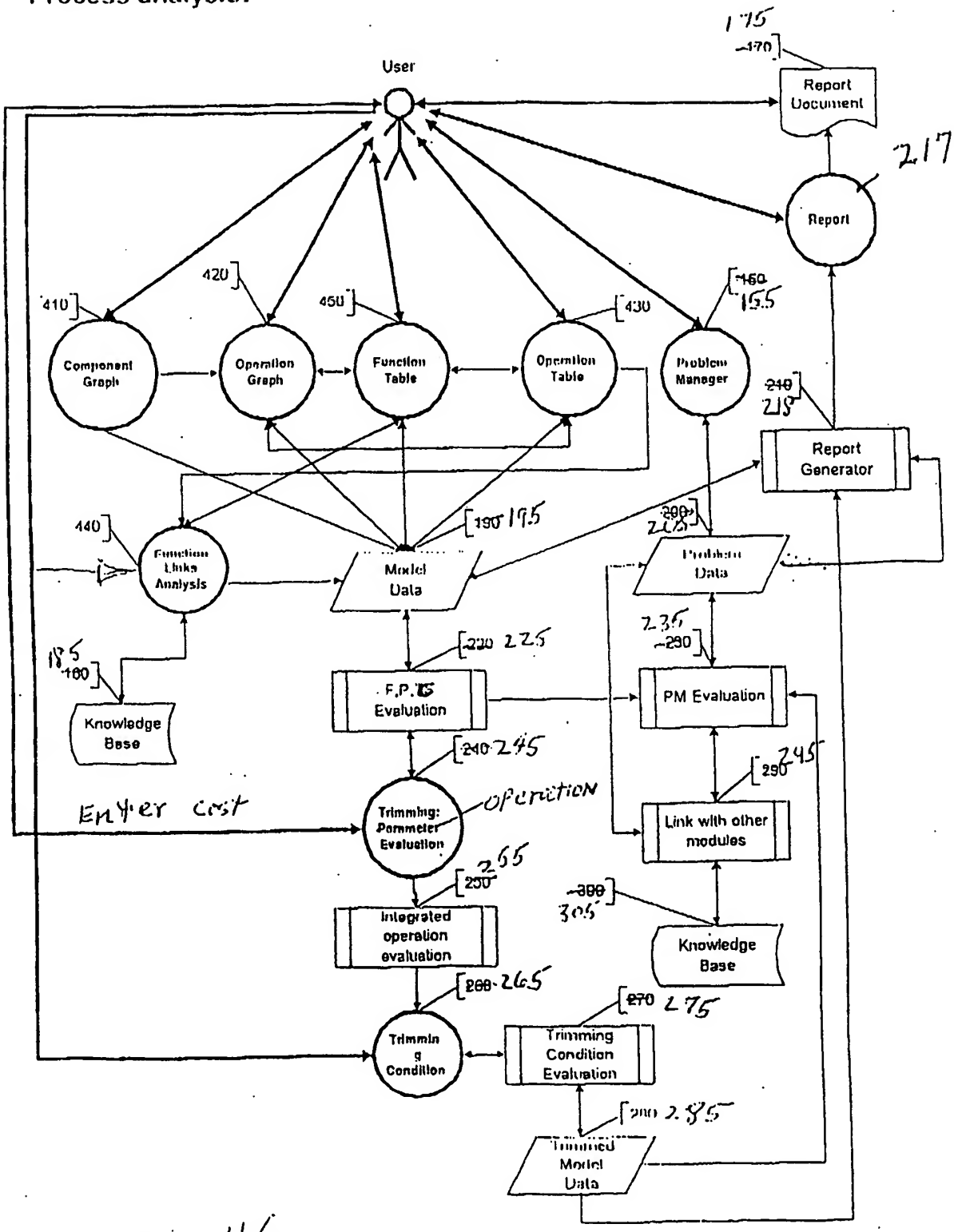
PROCESS SYSTEM ANALYSIS (PSA)



PROCESS Analysis STAGE



Process analysis:



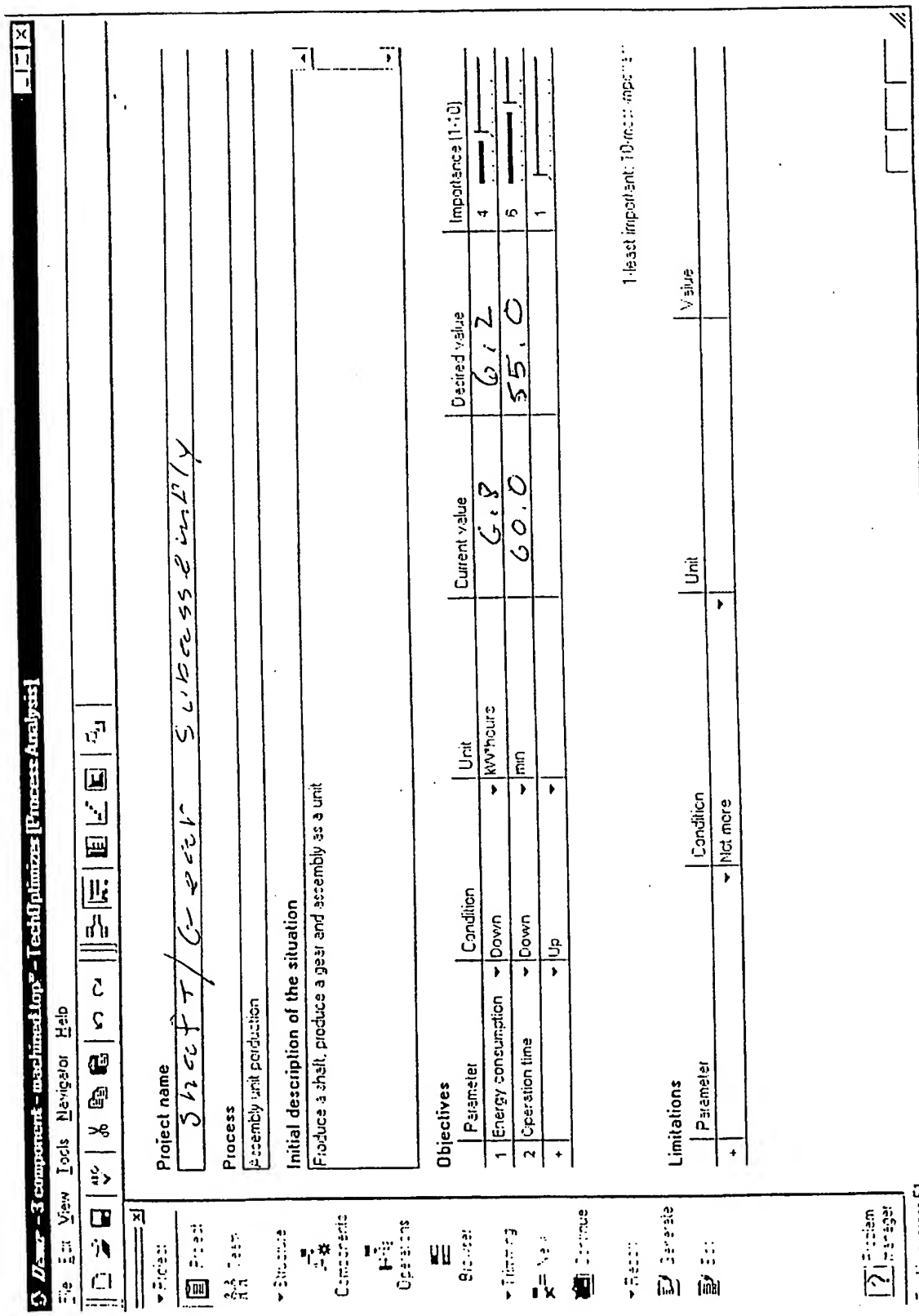
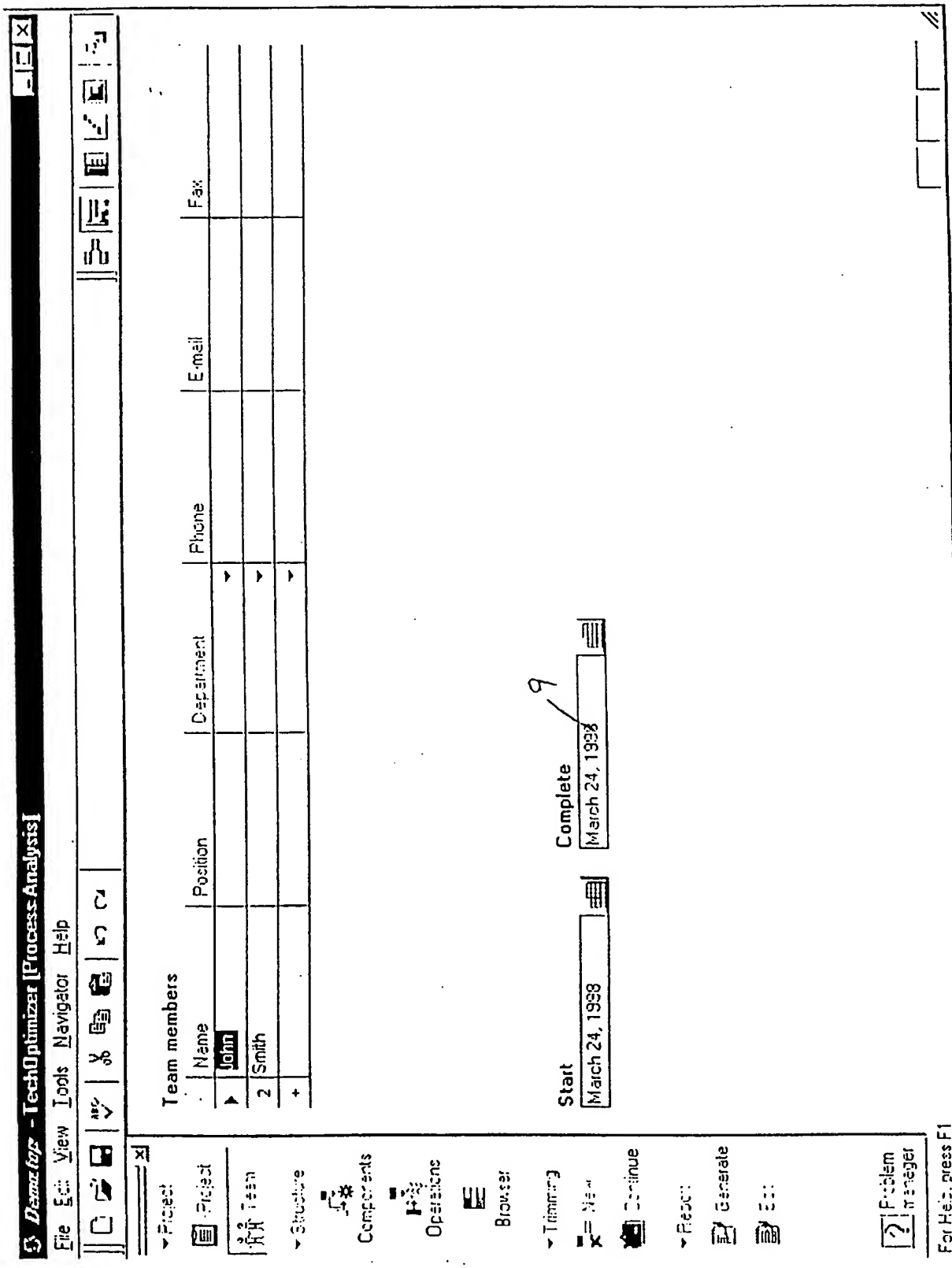
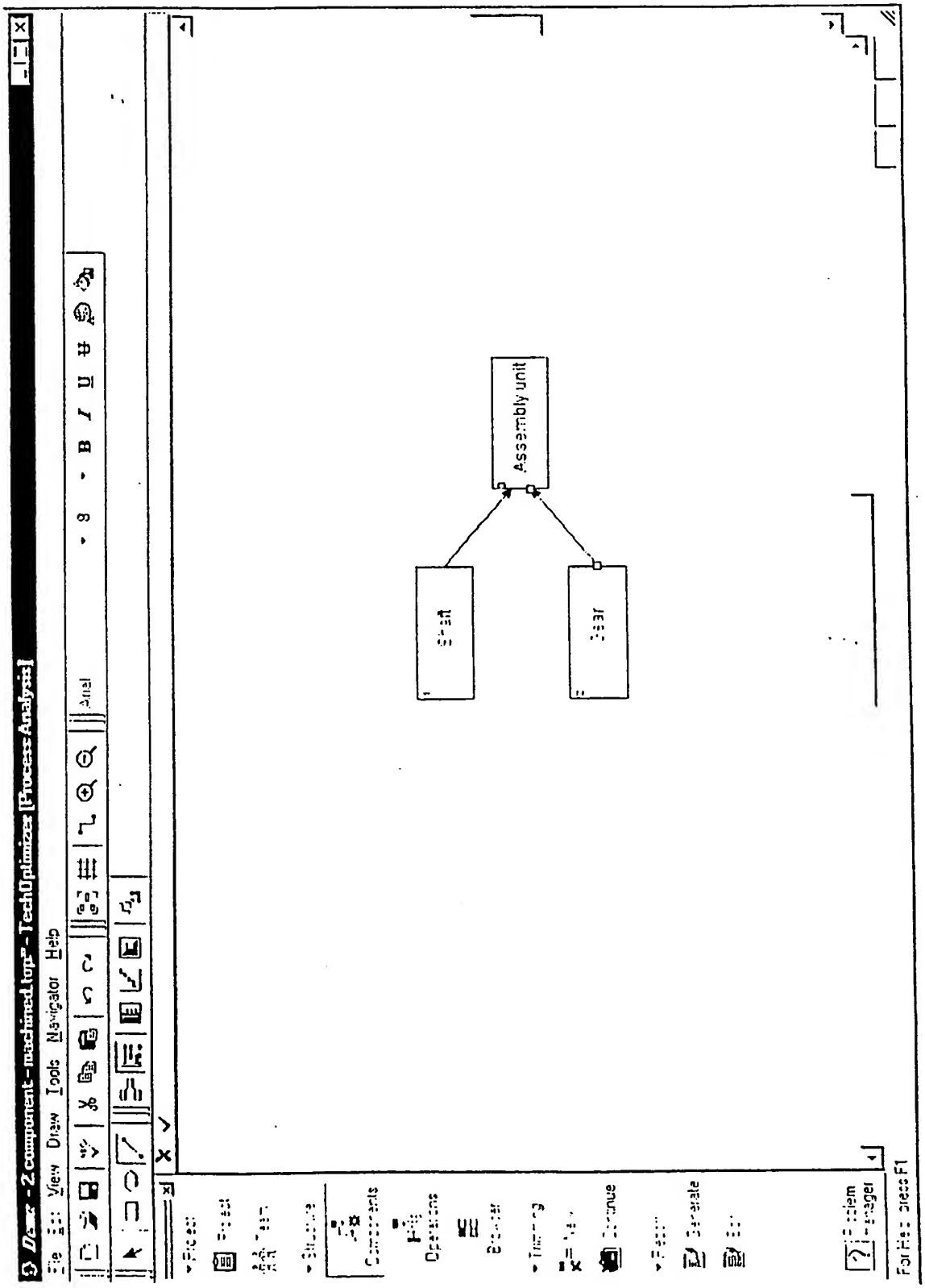

3 component - machined.lop* - TechOptimizer [Process Analysis]
File Edit View Tools Navigator Help
Project
Project
Project name
Shaft/Gear Subassembly
Process
Assembly unit production
Structure
Components
Operations
Initial description of the situation
Produce a shaft, produce a gear and assembly as a unit
Objectives
Parameter
Condition
Unit
Current value
Desired value
Importance (1-10)
1 Energy consumption
Down
kWhours
6.8
6.2
4
2 Operation time
Down
min
60.0
55.0
5
Up
1
1=least important; 10=most important
Limitations
Parameter
Condition
Unit
Value
Not more
Generate
Edit
Problem Manager
For Help, press F1

Fig 47

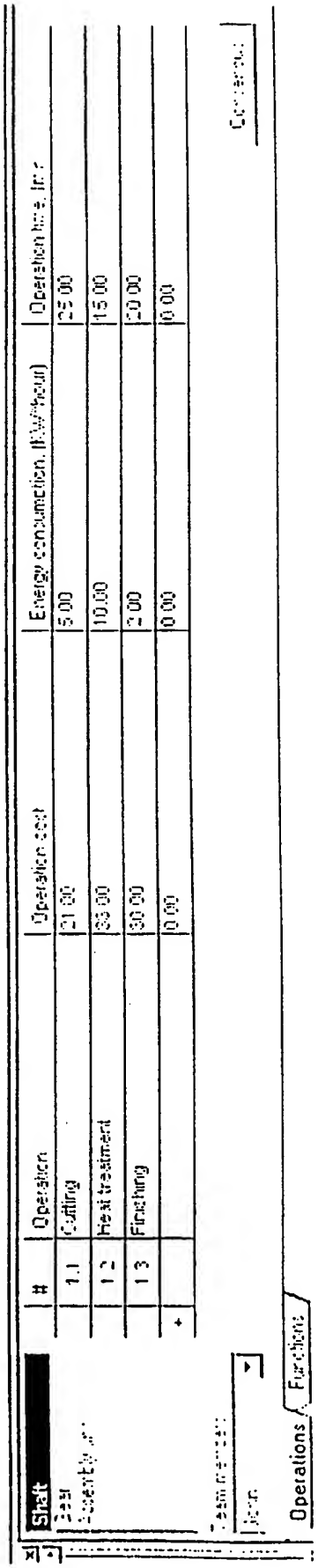

Desktop - TechOptimizer [Process Analysis]
File Edit View Tools Navigator Help
Project
Project
Team
Structure
Components
Operations
Browser
Timming
Continue
Report
Generate
Problem Manager
Team members
Name
Position
Department
Phone
E-mail
Fax
John
2
Smith
Start
March 24, 1998
Complete
March 24, 1998
9
For Help, press F1

4 8

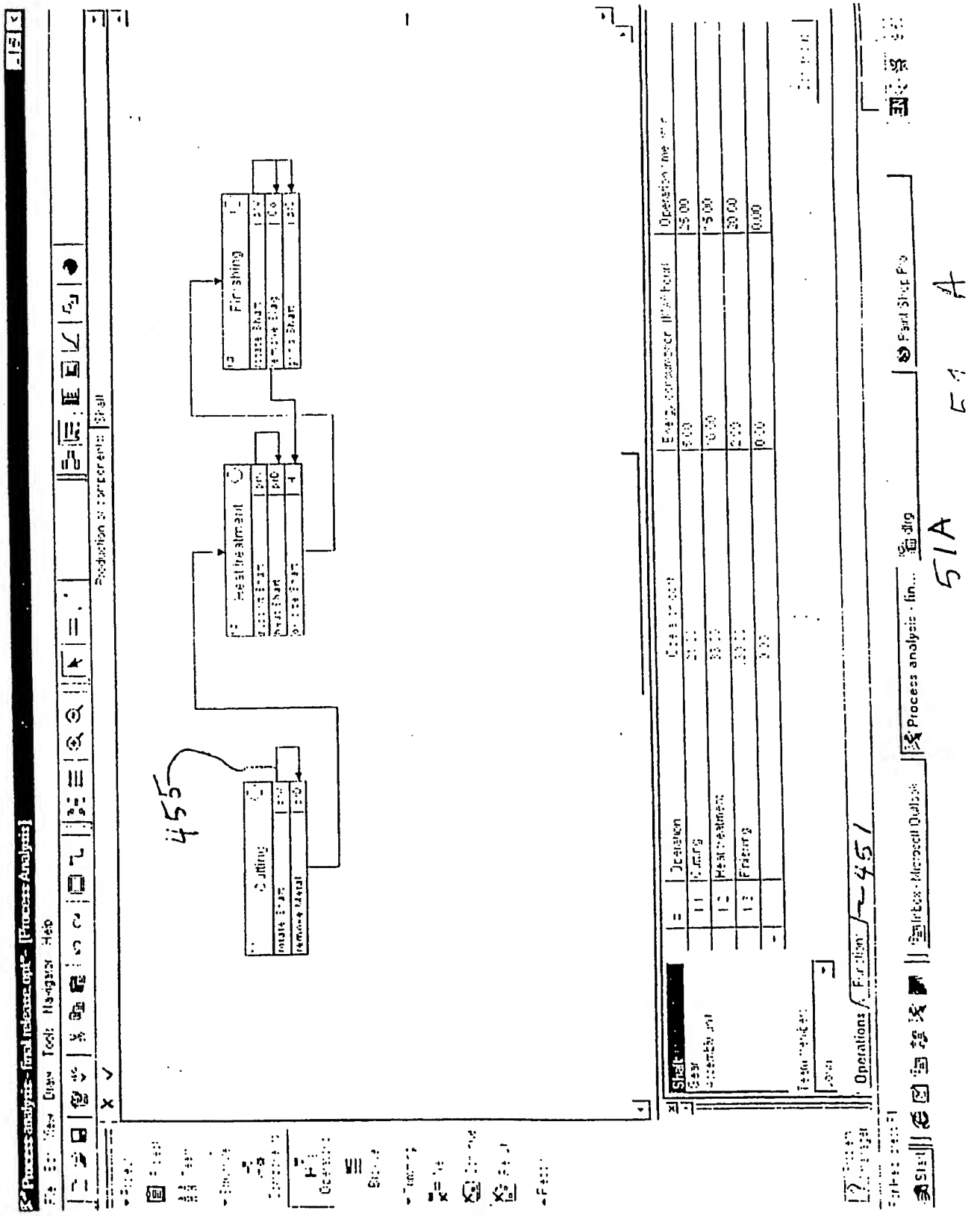


4/9

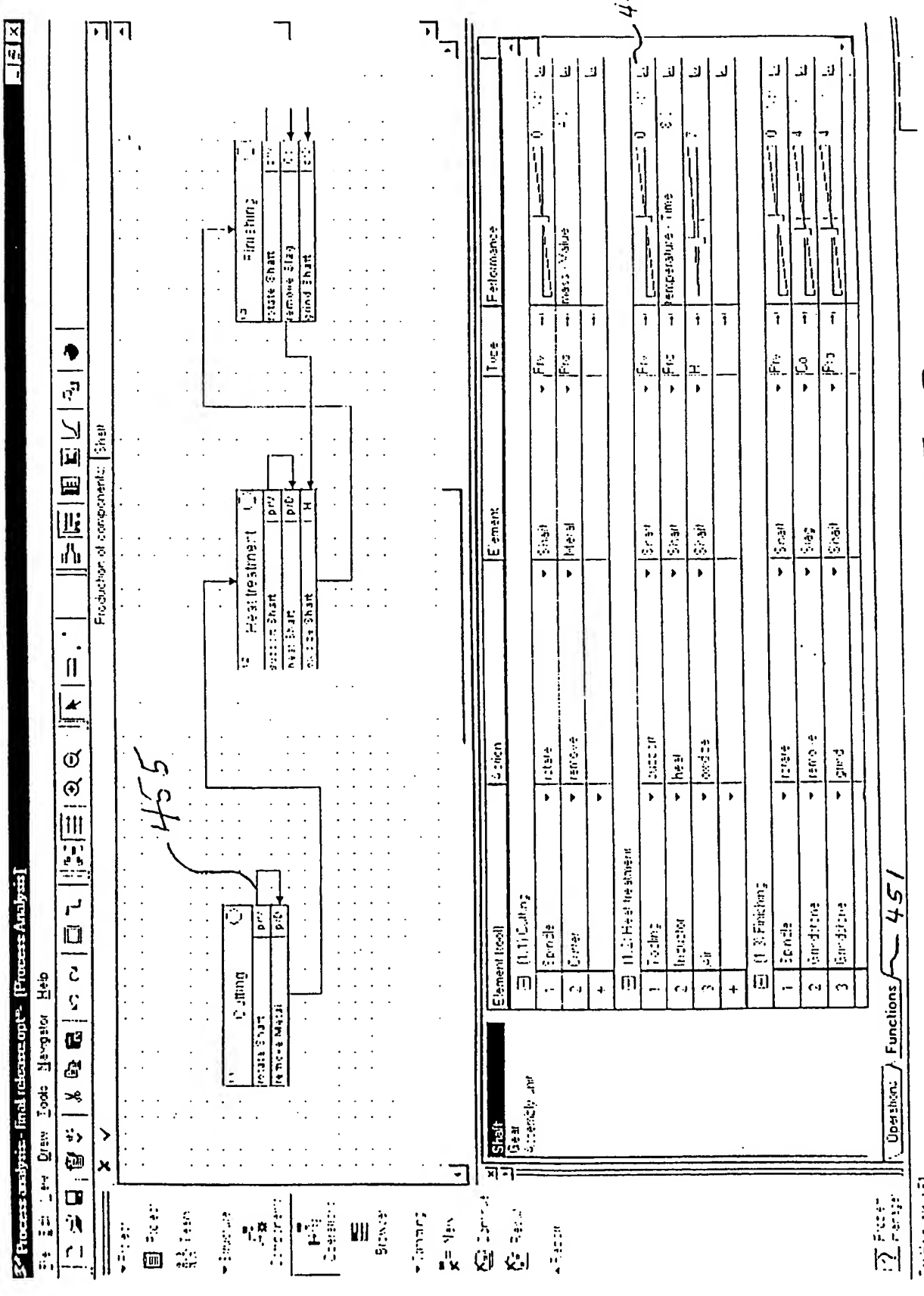
31/50

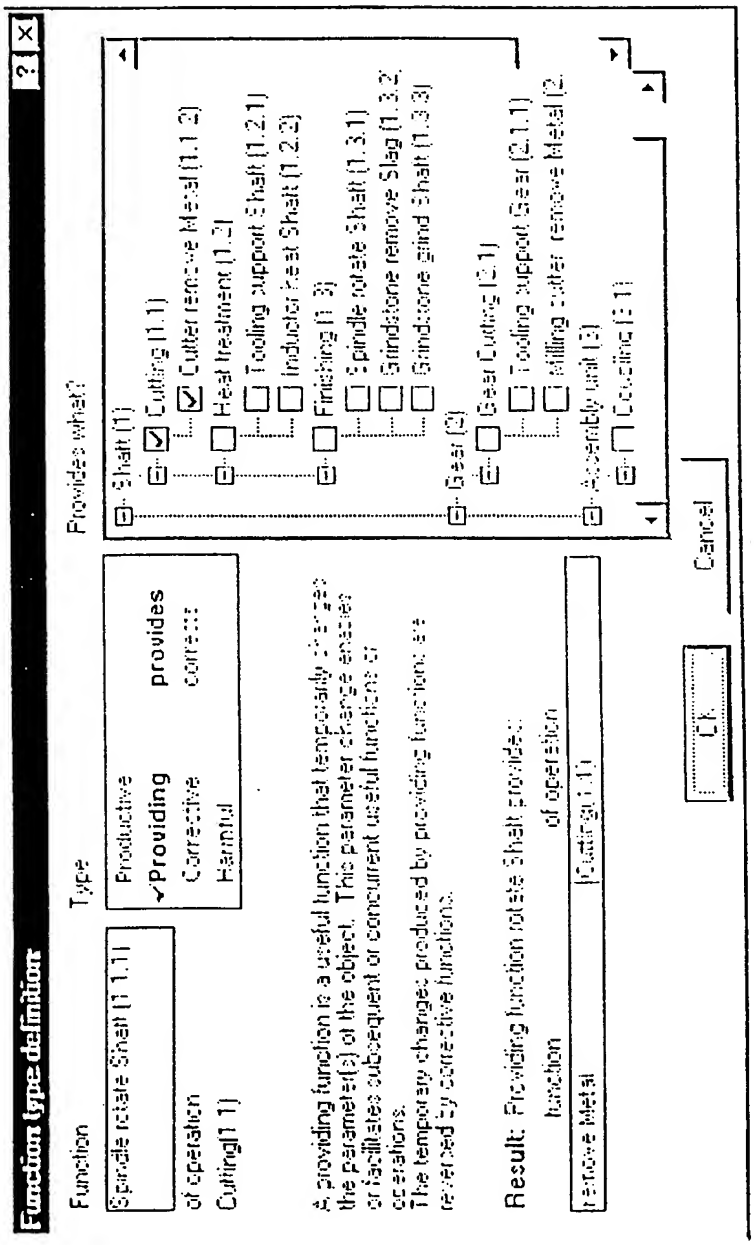

Shaft
Base
Assembly
Operations
Functions
#
Operation
Operation cost
Energy consumption (kW/Hour)
Operation time (m
1.1
Cutting
21.00
5.00
25.00
1.2
Heat treatment
83.00
10.00
15.00
1.3
Finishing
30.00
2.00
20.00
0.00
0.00
0.00

50

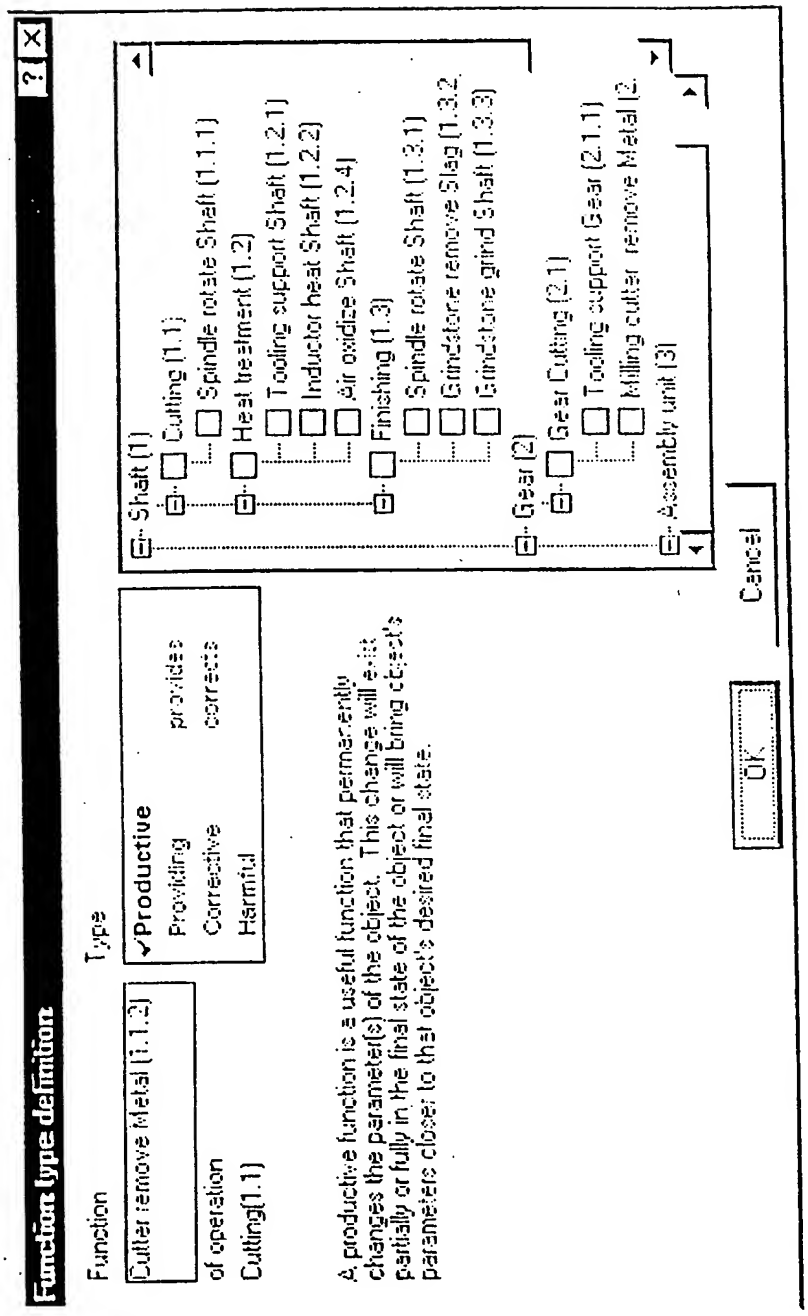

Process analysis - final release.opt* - [Process Analysis]
File Edit View Draw Tools Navigate Help
Production of component: Shaft
Cutting
Heat treatment
Finishing
455
Shaft
Operations / Function
451
Process analysis - fin...
Microsoft Outlook
Paint Shop Pro
Start

51A

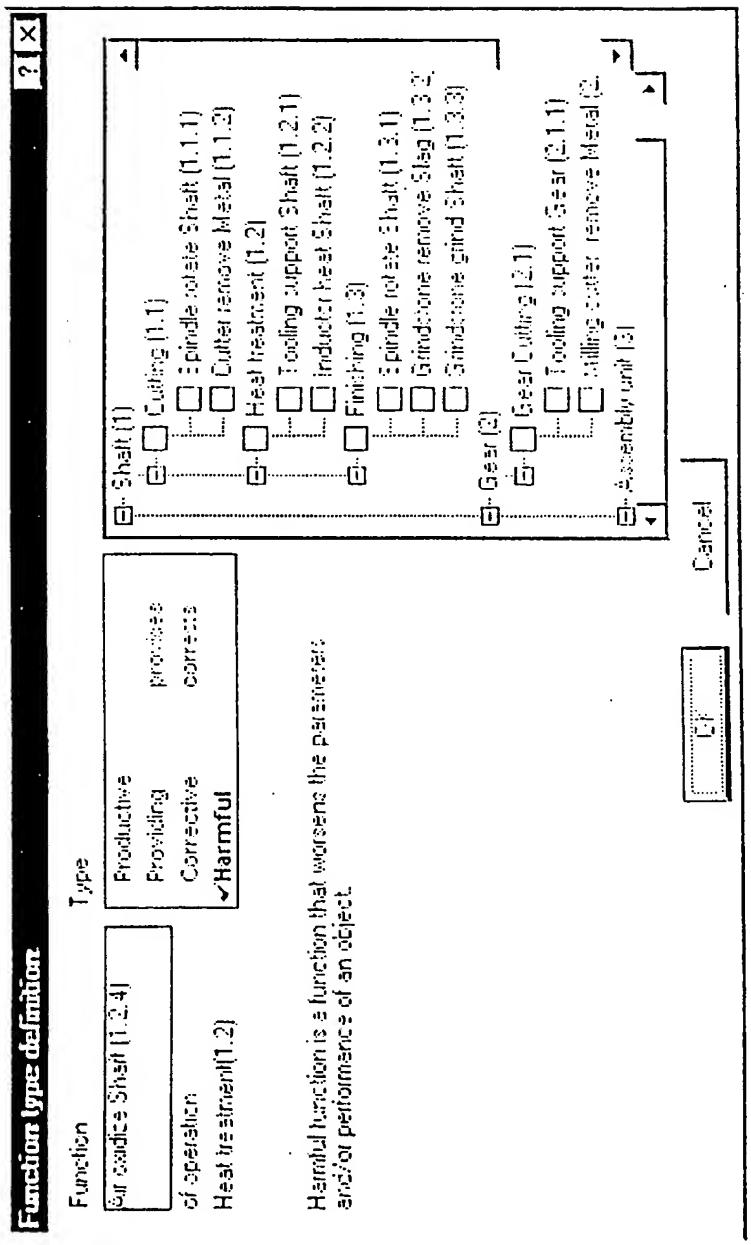

Process Analysis - final reference.apa - [Process Analysis]
File Edit View Draw Tools Navigator Help
Production of components: Shaft
Cutting
Heat treatment
Finishing
455
451
453
Operations
Functions
Element (tool)
Action
Element
Type
Performance
Shaft
Gear
Assembly unit
Cutting
Heat treatment
Finishing
Spindle
Cutter
Turning
Cutting
Heat treatment
Induction
Oil
Finishing
Spindle
Grinding
Grinding
Shaft
Step
Mass - Value
Temperature - Time


Function type definition
Function
Spindle rotate Shaft (1.1.1)
of operation
Cutting(1.1)
Type
Productive
Providing
Corrective
Harmful
provides
corrects
A providing function is a useful function that temporarily changes the parameter(s) of the object. This parameter change enables or facilitates subsequent or concurrent useful functions or operations.
The temporary changes produced by providing functions are reversed by corrective functions.
Result: Providing function rotate Shaft provides:
function
of operation
Remove Metal
Cutting(1.1)
Provides what?
Shaft (1)
Cutting (1.1)
Cutter remove Metal (1.1.2)
Heat treatment (1.2)
Tooling support Shaft (1.2.1)
Inductor heat Shaft (1.2.2)
Finishing (1.3)
Spindle rotate Shaft (1.3.1)
Grindstone remove Slag (1.3.2)
Grindstone grind Shaft (1.3.3)
Gear (2)
Gear Cutting (2.1)
Tooling support Gear (2.1.1)
Milling cutter remove Metal (2.
Assembly unit (3)
Coupling (3.1)
OK
Cancel

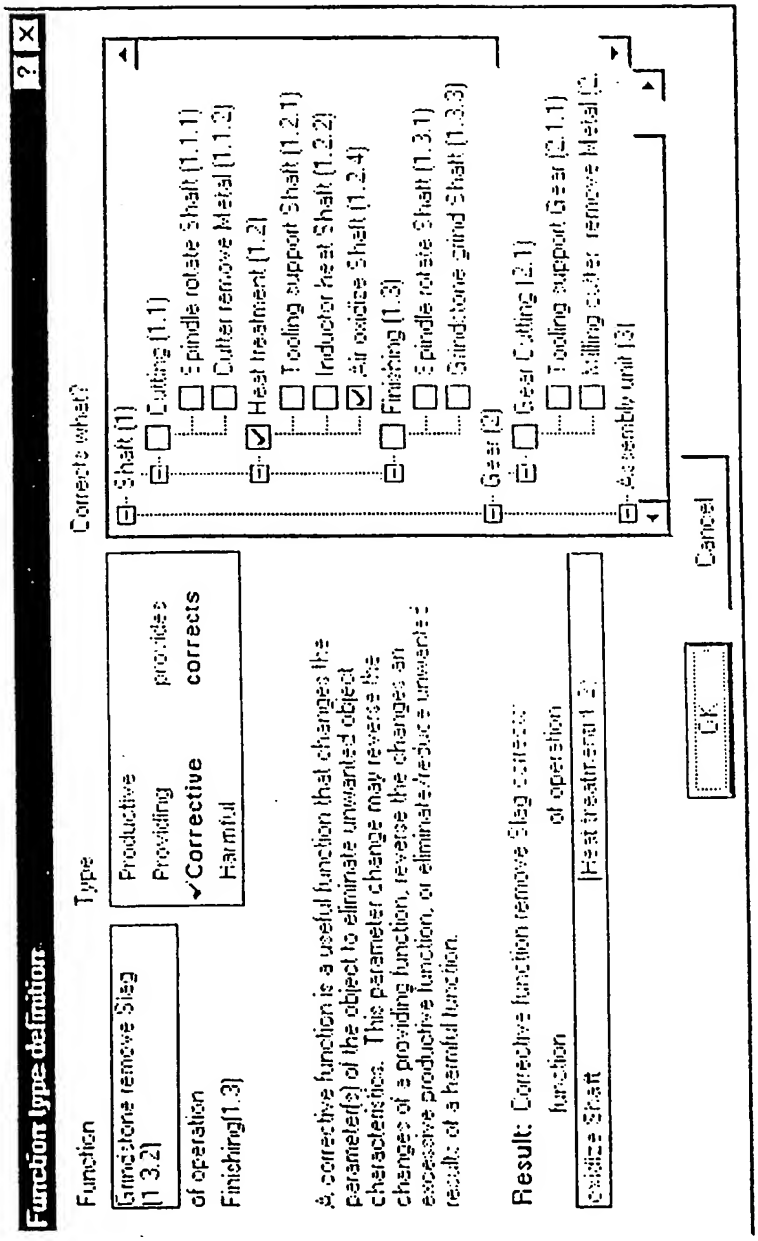
52

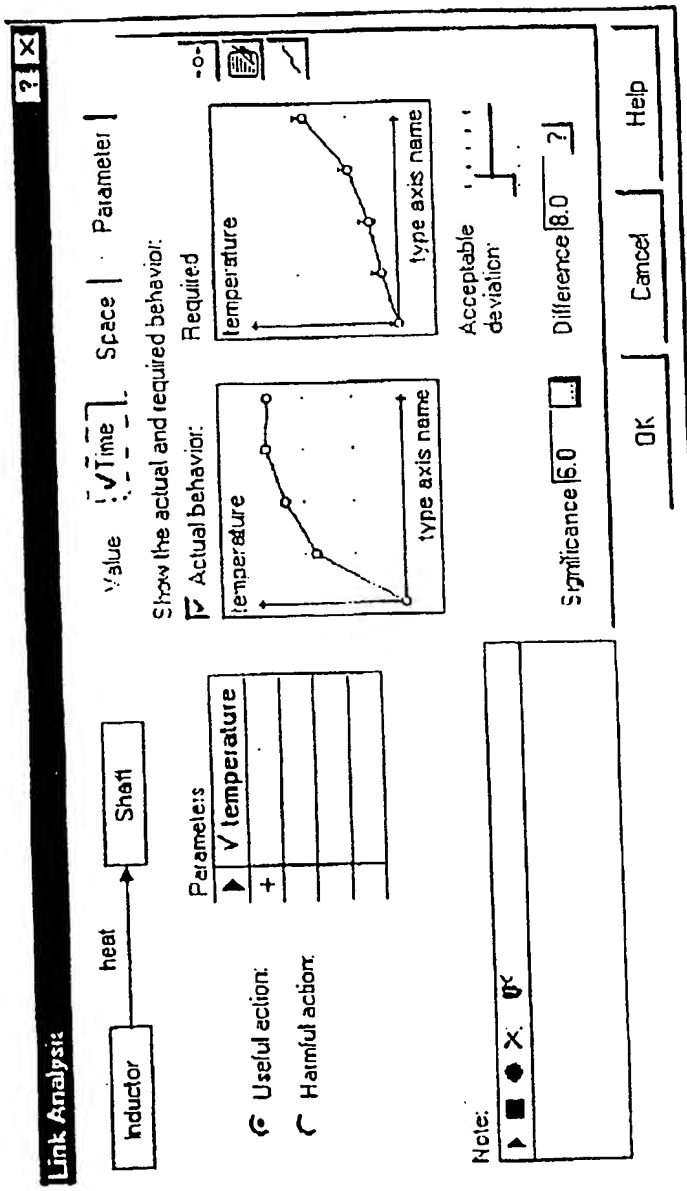

Function type definition
Function
Cutter remove Metal (1.1.2)
of operation
Cutting(1.1)
Type
✓Productive
Providing
Corrective
Harmful
provides
corrects
A productive function is a useful function that permanently changes the parameter(s) of the object. This change will exist partially or fully in the final state of the object or will bring object's parameters closer to that object's desired final state.
Shaft (1)
Cutting (1.1)
Spindle rotate Shaft (1.1.1)
Heat treatment (1.2)
Tooling support Shaft (1.2.1)
Inductor heat Shaft (1.2.2)
Air oxidize Shaft (1.2.4)
Finishing (1.3)
Spindle rotate Shaft (1.3.1)
Grindstone remove Slag (1.3.2
Grindstone grind Shaft (1.3.3)
Gear (2)
Gear Cutting (2.1)
Tooling support Gear (2.1.1)
Milling cutter remove Metal (2.
Assembly unit (3)
OK
Cancel

53

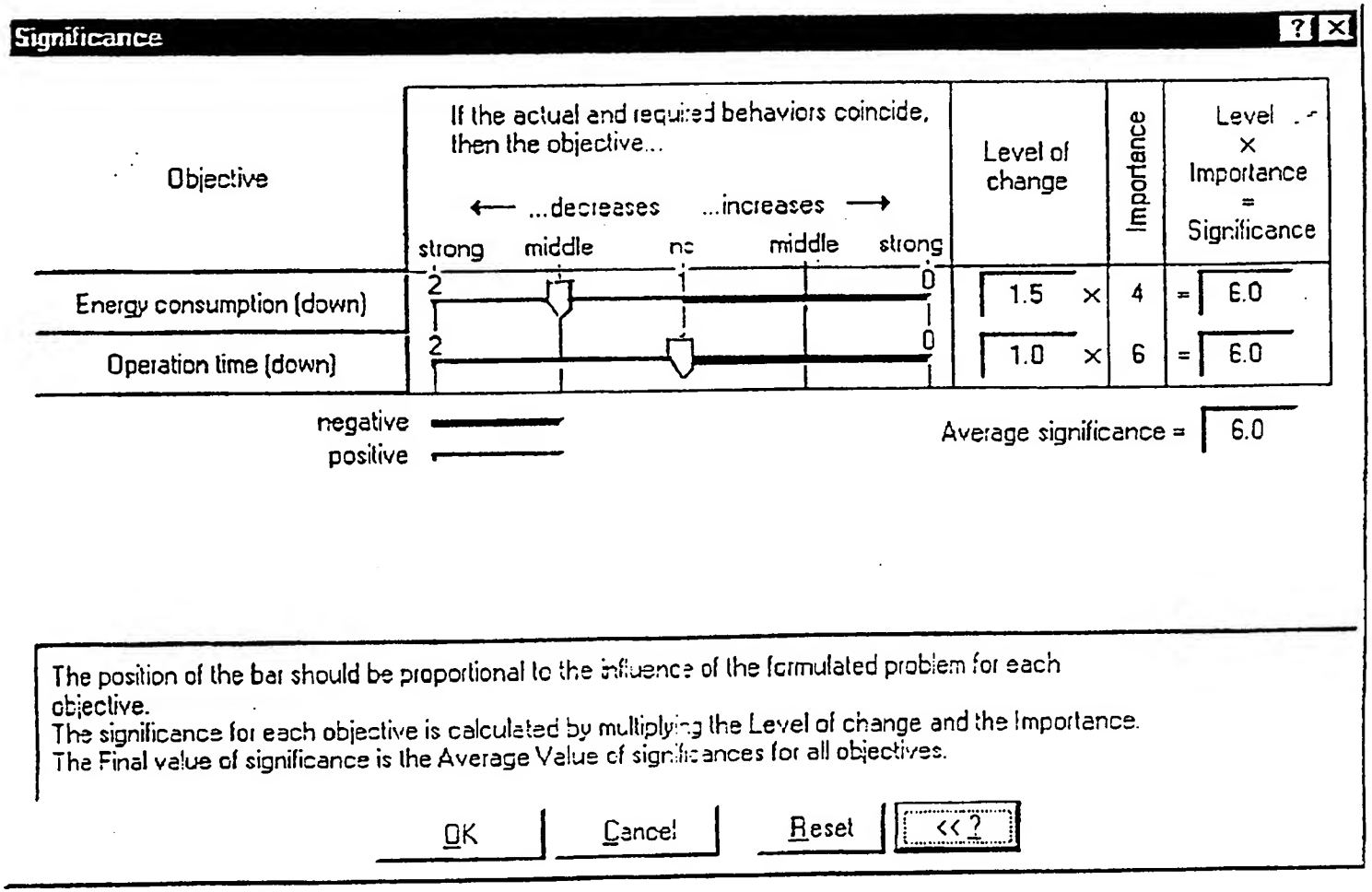

Function type definition
Function
Type
Productive
Providing
Corrective
Harmful
provides
corrects
Shaft (1)
Cutting (1.1)
Spindle rotate Shaft (1.1.1)
Cutter remove Metal (1.1.2)
Heat treatment (1.2)
Tooling support Shaft (1.2.1)
Inductor heat Shaft (1.2.2)
Finishing (1.3)
Spindle rotate Shaft (1.3.1)
Grindstone remove Slag (1.3.2)
Grindstone grind Shaft (1.3.3)
Gear (2)
Gear Cutting (2.1)
Tooling support Gear (2.1.1)
Milling cutter remove Metal (2.
Assembly unit (3)
Cancel
Harmful function is a function that worsens the parameters and/or performance of an object.

14


Function type definition
Function
Grind/stone remove Slag (1.3.2)
of operation
Finishing(1.3)
Type
Productive
Providing
provides
Corrective
corrects
Harmful
Corrects what?
Shaft (1)
Cutting (1.1)
Spindle rotate Shaft (1.1.1)
Cutter remove Metal (1.1.2)
Heat treatment (1.2)
Tooling support Shaft (1.2.1)
Inductor heat Shaft (1.2.2)
Air oxidize Shaft (1.2.4)
Finishing (1.3)
Spindle rotate Shaft (1.3.1)
Grind/stone grind Shaft (1.3.3)
Gear (2)
Gear Cutting (2.1)
Tooling support Gear (2.1.1)
Milling cutter remove Metal (2.
Assembly unit (3)
A corrective function is a useful function that changes the parameter(s) of the object to eliminate unwanted object characteristics. This parameter change may reverse the changes of a providing function, reverse the changes an excessive productive function, or eliminate/reduce unwanted result of a harmful function.
Result: Corrective function remove Slag connects
function
of operation
Grind/stone Shaft
Heat treatment (1.2)
OK
Cancel


Link Analysis:
Inductor
heat
Shaft
Value
Time
Space
Parameter
Show the actual and required behavior:
Actual behavior:
Required
temperature
type axis name
Parameters
temperature
Useful action:
Harmful action:
Acceptable deviation:
Difference 8.0
Significance 6.0
OK
Cancel
Help
Note:

56


Significance
Objective
If the actual and required behaviors coincide, then the objective...
← ...decreases ...increases →
strong middle no middle strong
2 1 0
Energy consumption (down)
Operation time (down)
Level of change
Importance
Level × Importance = Significance
1.5 × 4 = 6.0
1.0 × 6 = 6.0
negative
positive
Average significance = 6.0
The position of the bar should be proportional to the influence of the formulated problem for each objective.
The significance for each objective is calculated by multiplying the Level of change and the Importance.
The Final value of significance is the Average Value of significances for all objectives.
OK
Cancel
Reset
<< ?

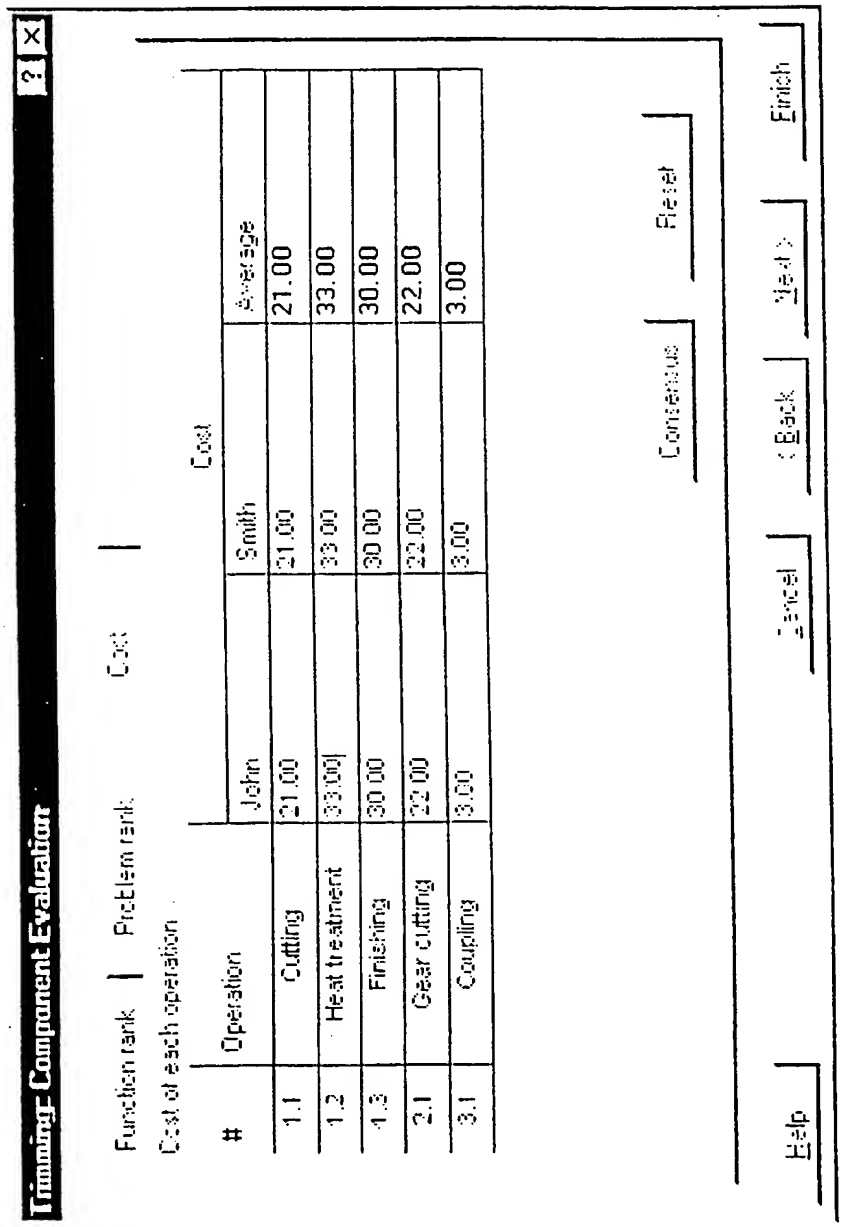
57

Function rank
Problem rank
Rank the function for each operation
Function rank
| Operation | John | Smith | Average
1.1 | Cutting | 8.33 | 8.33 | 8.33
1.2 | Heat treatment | 8.33 | 8.33 | 8.33
1.3 | Finishing | 10.00 | 10.00 | 10.00
2.1 | Gear cutting | 8.33 | 8.33 | 8.33
3.1 | Coupling | 10.00 | 10.00 | 10.00
10 - most functional 0 - least
Consensus
Reset
Help
Cancel
< Back
Next >
Finish

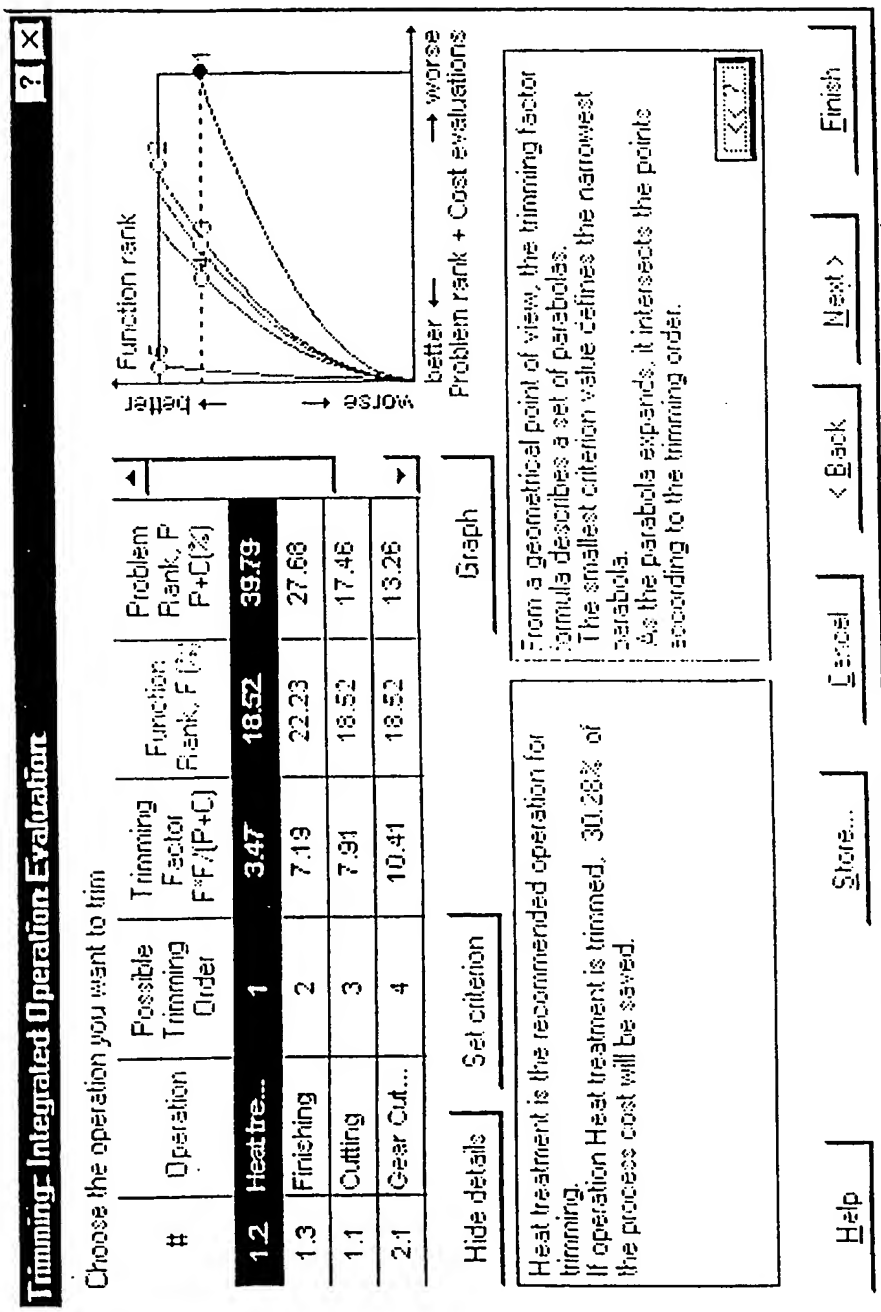
88

Component Evaluation
Function rank
Problem rank
Gear
Rank the problem for each operation
Problem rank
#
Operation
John
Smith
Average
1.1
Cutting
4.00
4.00
4.00
1.2
Heat treatment
10.00
10.00
10.00
1.3
Finishing
7.20
7.20
7.20
2.1
Gear cutting
3.00
3.00
3.00
3.1
Coupling
1.00
1.00
1.00
Comments
Reset
Help
Cancel
< Back
Next >
Finish

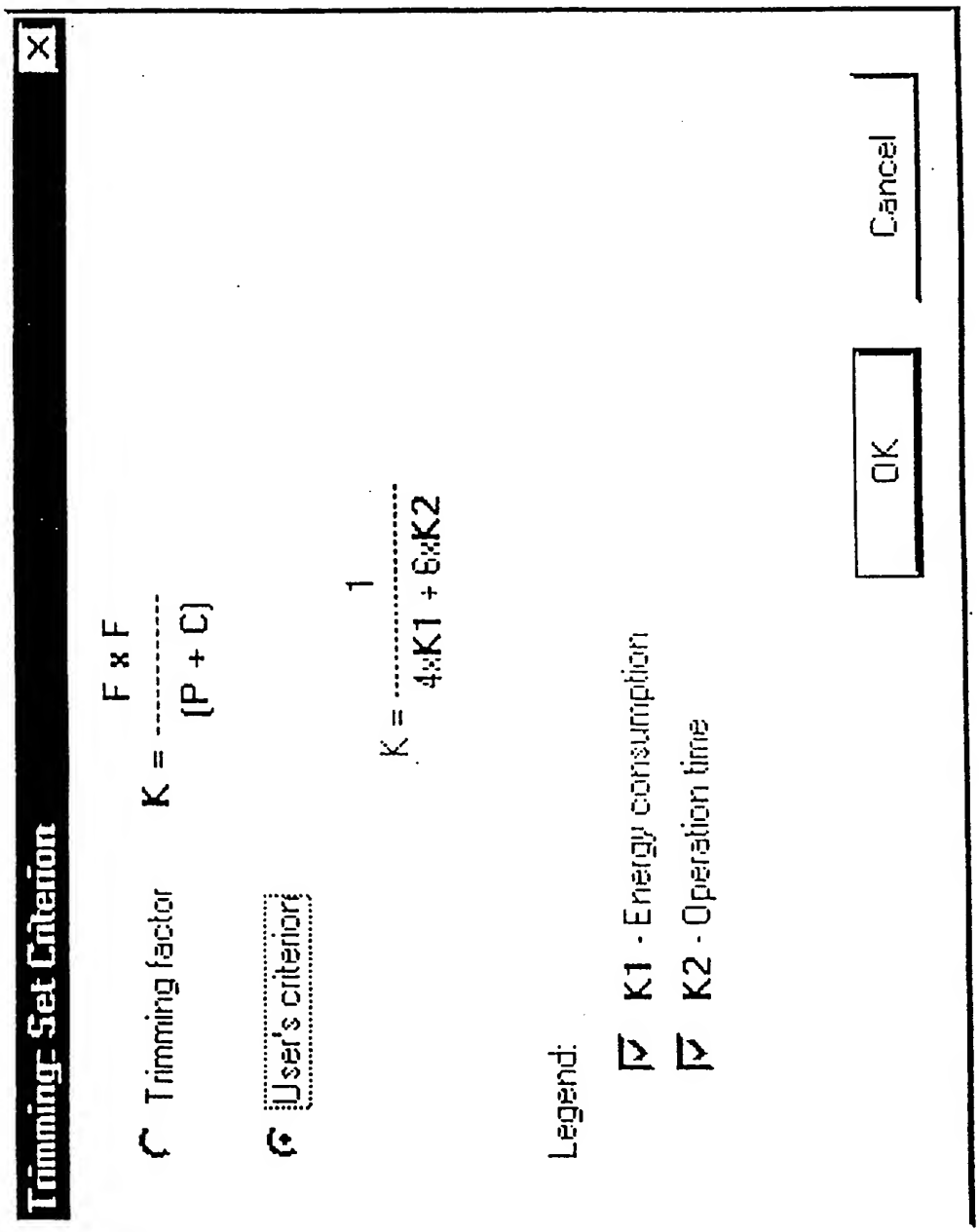
59A


Trimming Component Evaluation
Function rank
Problem rank
Cost
Cost of each operation
Cost
Operation John Smith Average
1.1 Cutting 21.00 21.00 21.00
1.2 Heat treatment 33.00 33.00 33.00
1.3 Finishing 30.00 30.00 30.00
2.1 Gear cutting 22.00 22.00 22.00
3.1 Coupling 3.00 3.00 3.00
Consensus
Reset
Help
Cancel
< Back
Next >
Finish

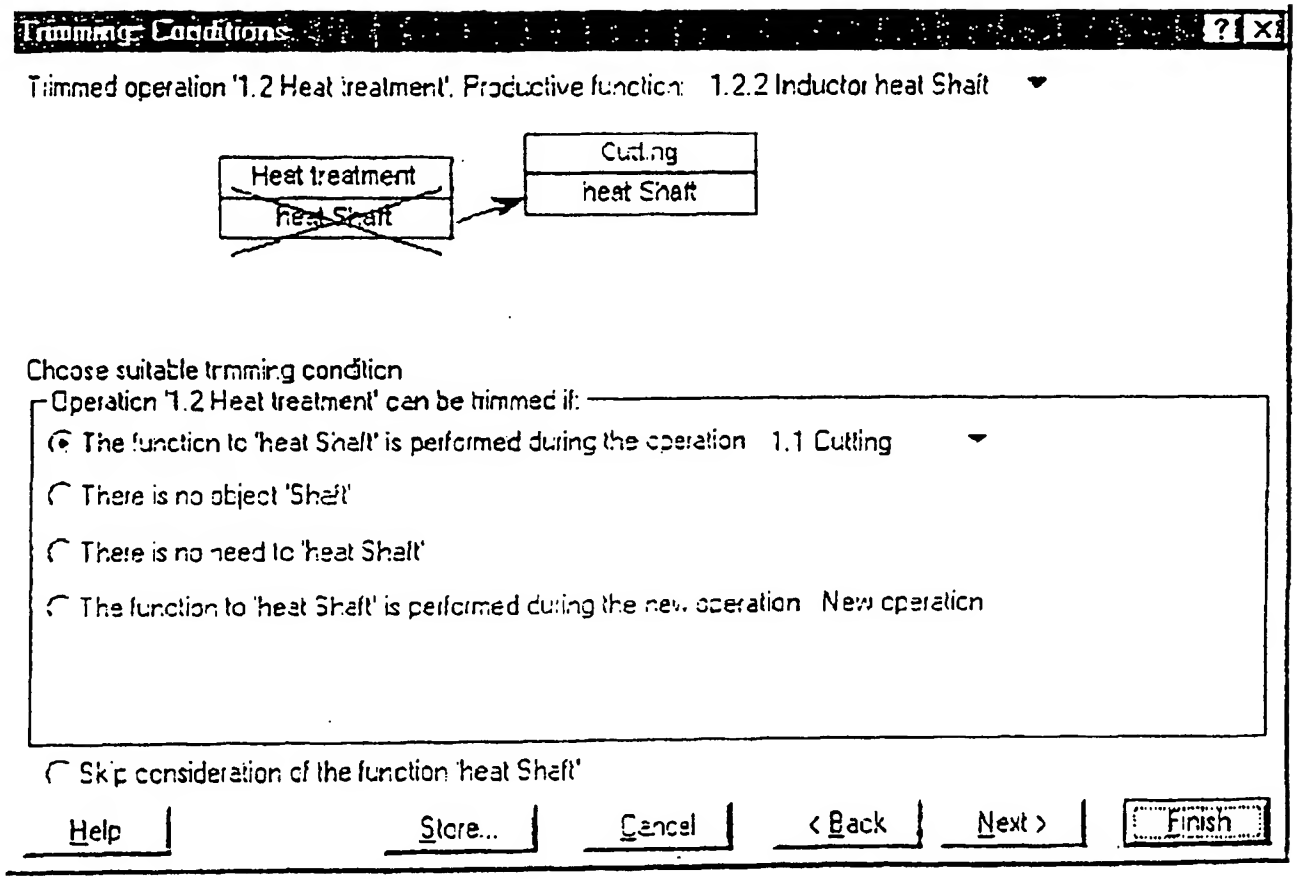
5 9 B


Trimming: Integrated Operation Evaluation
Choose the operation you want to trim
| Operation | Possible Trimming Order | Trimming Factor F*F'/(P+C) | Function Rank, F | Problem Rank, P P+C(%)
1.2 Heat tre... 1 3.47 18.52 39.79
1.3 Finishing 2 7.19 22.23 27.68
1.1 Cutting 3 7.91 18.52 17.46
2.1 Gear Cut... 4 10.41 18.52 13.26
Hide details
Set criterion
Graph
Heat treatment is the recommended operation for trimming.
If operation Heat treatment is trimmed, 30.28% of the process cost will be saved.
From a geometrical point of view, the trimming factor formula describes a set of parabolas.
The smallest criterion value defines the narrowest parabola.
As the parabola expands, it intersects the points according to the trimming order.
OK
Function rank
better
worse
better
worse
Problem rank + Cost evaluations
Help
Store...
Cancel
< Back
Next >
Finish

60

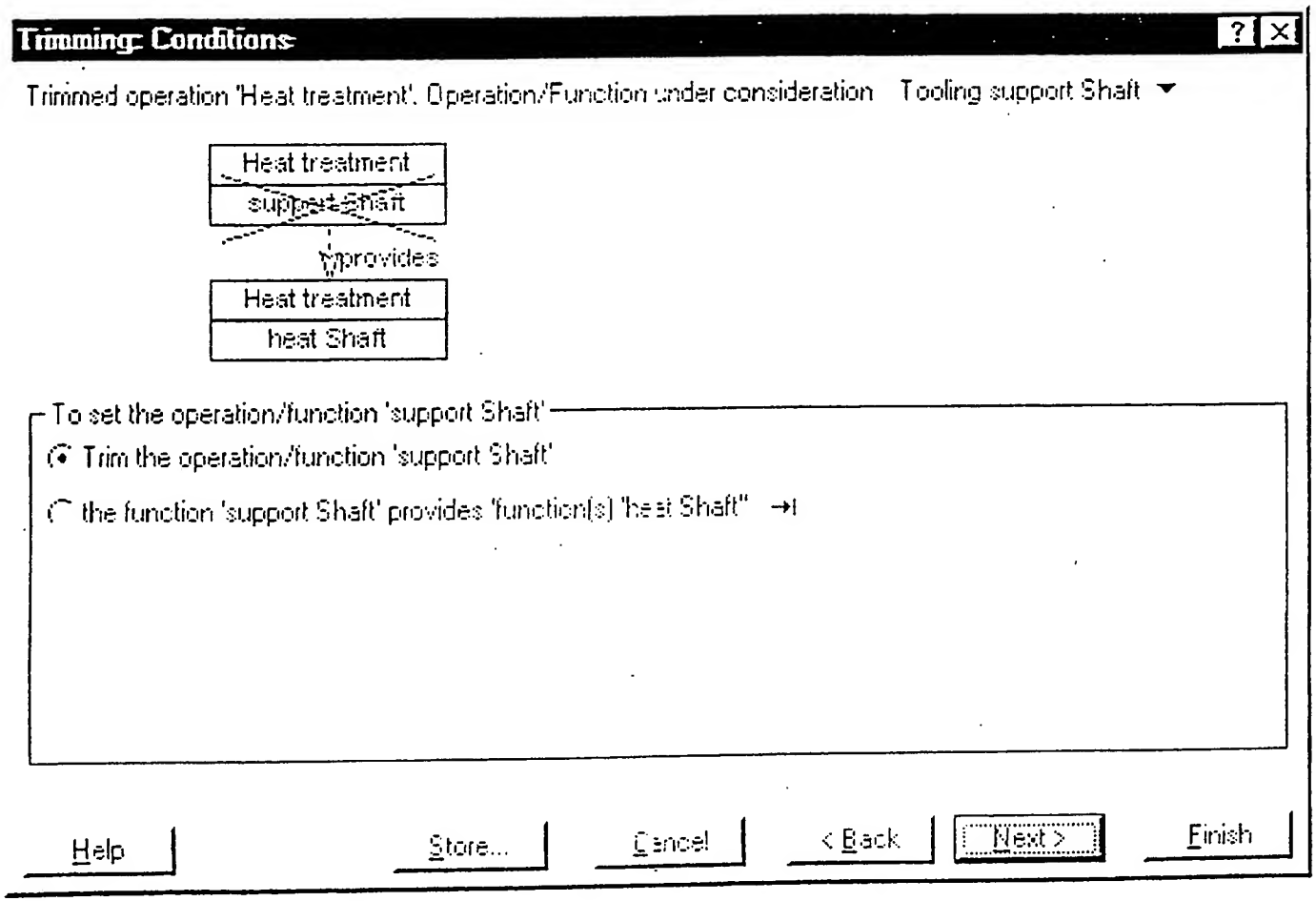

Trimming Set Criterion
Trimming factor
K = F x F / (P + C)
User's criterion
K = 1 / 4xK1 + 6xK2
Legend:
K1 - Energy consumption
K2 - Operation time
OK
Cancel

61

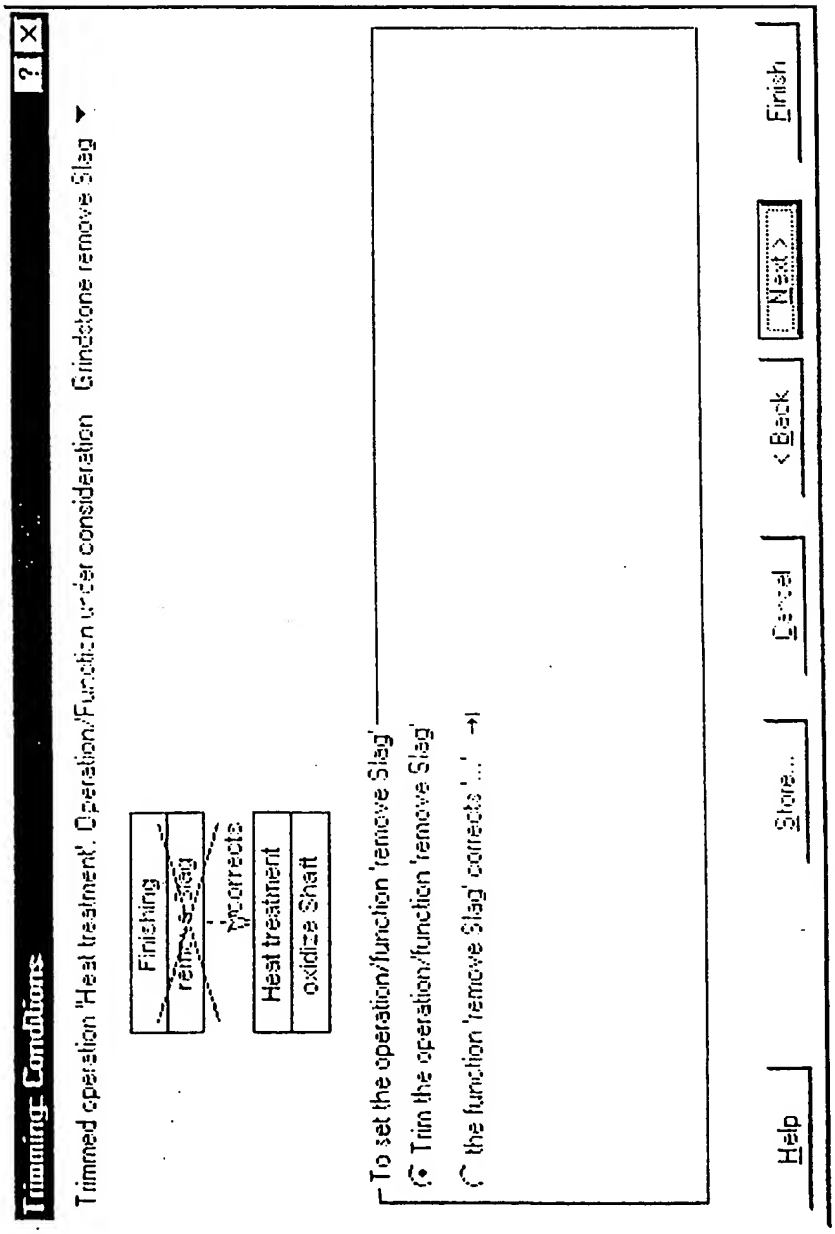

Trimming Conditions
Trimmed operation '1.2 Heat treatment'. Productive function: 1.2.2 Inductor heat Shaft
Heat treatment
Heat Shaft
Cutting
heat Shaft
Choose suitable trimming condition
Operation '1.2 Heat treatment' can be trimmed if:
The function to 'heat Shaft' is performed during the operation 1.1 Cutting
There is no object 'Shaft'
There is no need to 'heat Shaft'
The function to 'heat Shaft' is performed during the new operation New operation
Skip consideration of the function 'heat Shaft'
Help
Store...
Cancel
< Back
Next >
Finish

62

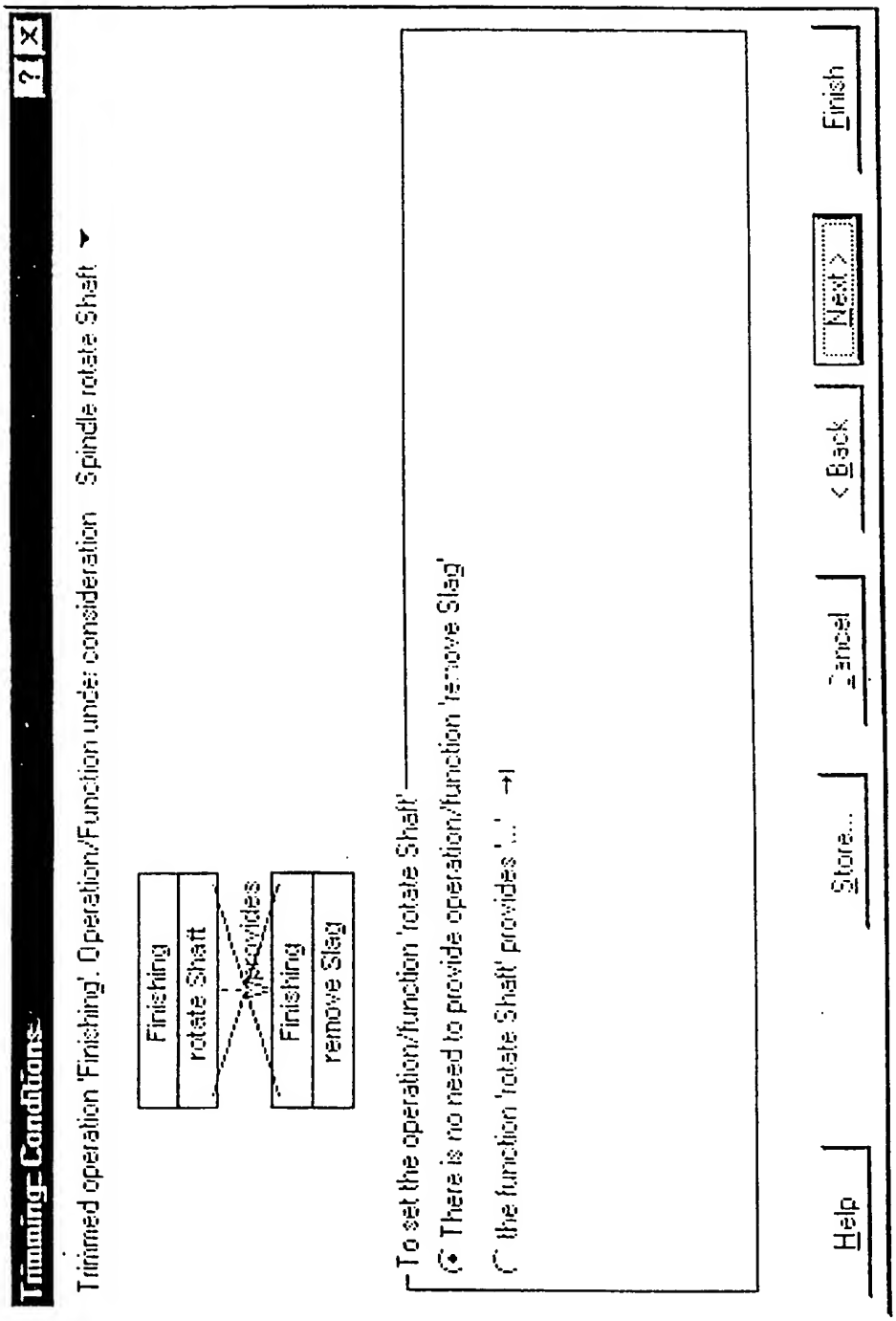
AUTOMATIC



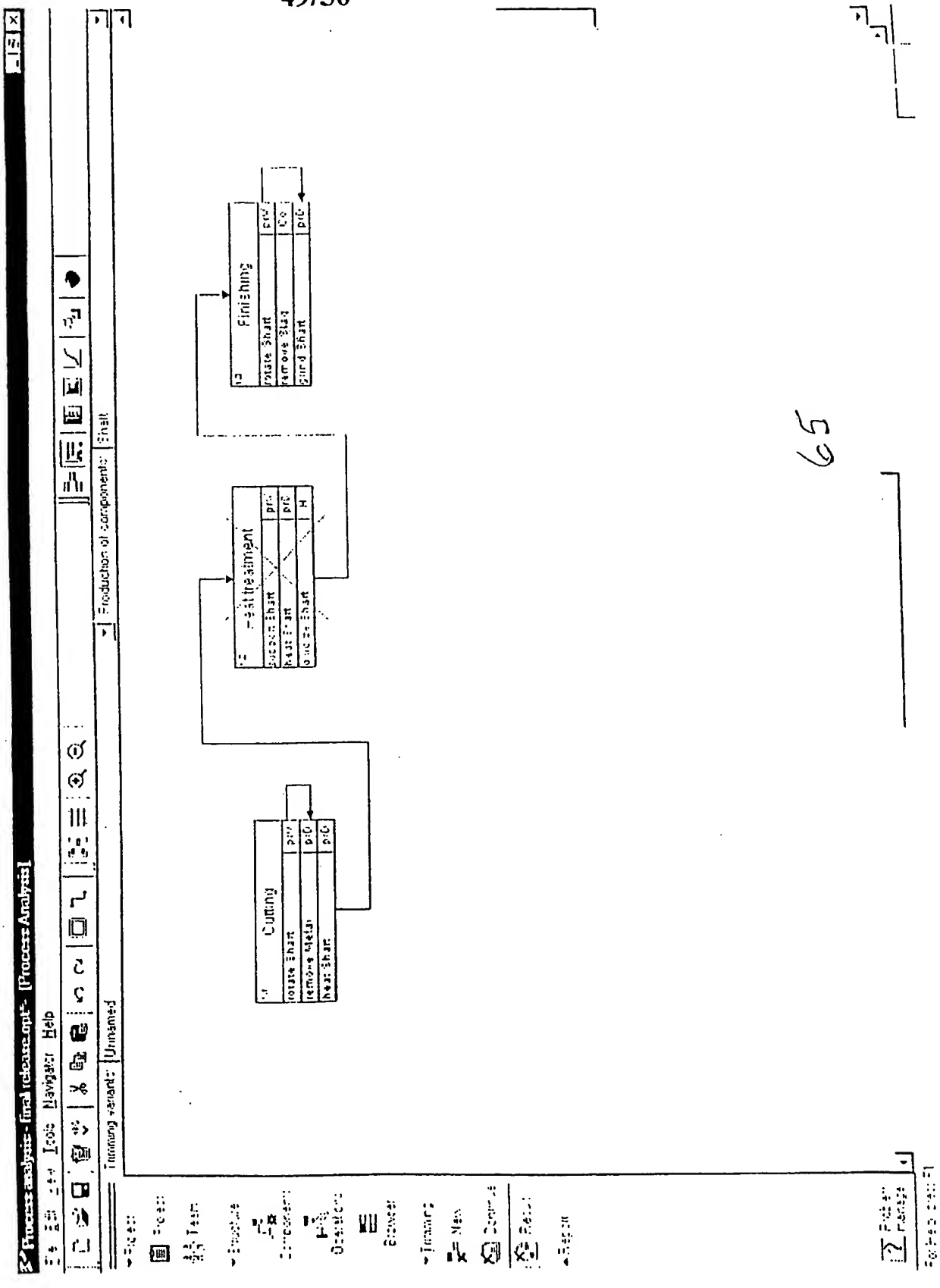
63 A


Trimming Conditions
Trimmed operation 'Heat treatment'. Operation/Function under consideration Grindstone remove Slag
Finishing
remove Slag
Incorrecte
Heat treatment
oxidize Shaft
To set the operation/function 'remove Slag'
Trim the operation/function 'remove Slag'
the function 'remove Slag' corrects '...'
Help
Store...
Cancel
< Back
Next >
Finish

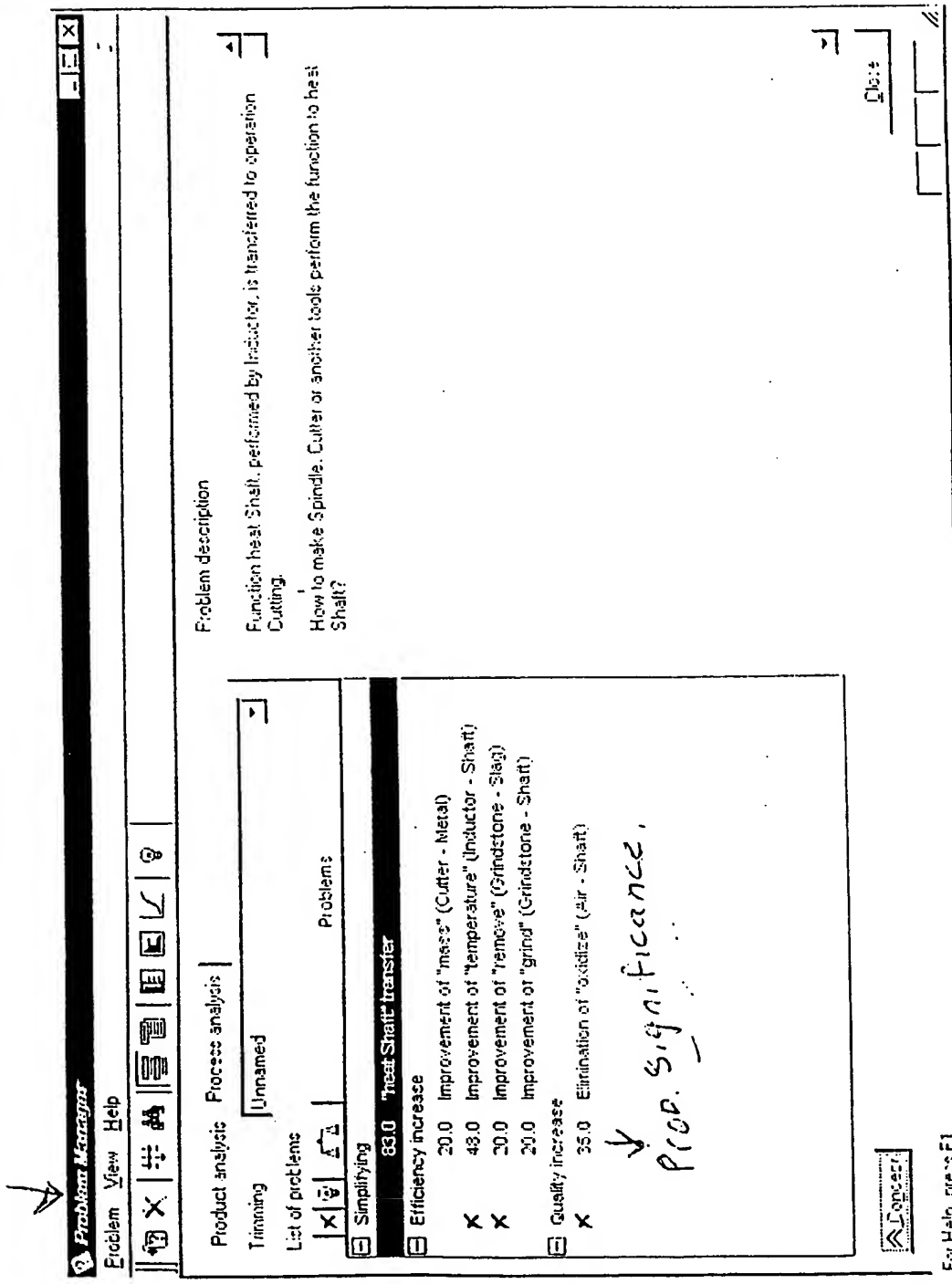
63


Trimming Conditions
Trimmed operation 'Finishing'. Operation/Function under consideration Spindle rotate Shaft
Finishing
rotate Shaft
provides
Finishing
remove Slag
To set the operation/function 'rotate Shaft'
There is no need to provide operation/function 'remove Slag'
the function 'rotate Shaft' provides '...'
Help
Store...
Cancel
< Back
Next >
Finish

64


Process analysis - final release.mpk - [Process Analysis]
File Edit View Tools Navigator Help
Planning variant: Unnamed
Production of components: Final
Cutting
rotate Shart
remove Shart
insert Shart
Finishing
rotate Shart
remove Shart
insert Shart

65



A

Prop. Significance,

6 C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/02067

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G06F 17/50
US CL : 703/2

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 703/2, 1, 6, 7, 13, 14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
U.S. Patent Database on STN, IEEE On-line Database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	US 5,754,447 A (GARDNER et al) 19 May 1998 (19.05.1998), Figure 4 and associated text starting column 4, line 59.	1-8, 10-23, 25-30
X	US 5,666,288 A (JONES et al) 09 September 1997 (09.09.1997), Figure 4 and associated text starting on column 7, line 3.	1-8, 10-23, 25-30
X	US 5,610,833 A (CHANG et al) 11 March 1997 (11.03.1997), starting on column 15, line 3.	1-8, 10-23, 25-30
X	US 5,541,849 A (ROSTOKER et al) 30 July 1996 (30.07.1996), Figure 5 and associated text starting in column 9, line 60.	1-8, 10-23, 25-30

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 March 2000 (23.03.2000)	04 APR 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Kevin J Teska Telephone No. (703)305-3900

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